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# EFFECT OF NOISE IN THE THREE-PARAMETER LOGISTIC MODEL

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DECEMBER, 1982

Prepared under the contract number N00014-81-C-0569, NR 150-467 with the Personnel and Training Research Programs Psychological Sciences Division Office of Naval Research

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R01-1068-71-001-84



SECURITY CLASSIFICATION OF THIS PAGE (When Date Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM	
ONR/Research Report 82-2  2. GOVT ACCESSION NO.  A) - A 13186	3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Substitle)	5. TYPE OF REPORT & PERIOD COVERED	
Effect of Noise in the Three-Parameter	Technical Report	
Logistic Model	6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(a)	8. CONTRACT OR GRANT NUMBER(#)	
Dr. Fumiko Samejima	N00014-81-C-0569	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
Personnel and Training Research Programs	PE: 61153N; PROJ: RR 042-04	
Office of Naval Research	TA: RR 042-04-01	
Arlington, VA 22217	WU: NR 150-467	
CONTROLLING OFFICE NAME AND ADDRESS	25 December 82	
	13. NUMBER OF PAGES	
14. MONITORING AGENCY NAME & ADDRESS(II different from Controlling Office)	15. SECURITY CLASS. (of this report)	
	Unclassified	
	154. DECLASSIFICATION/DOWNGRADING	
16. DISTRIBUTION STATEMENT (of this Report)	<u> </u>	
in whole or in part is permitted for any purpose government.  17. DISTRIBUTION STATEMENT (of the abotract entered in Block 20, if different from		
18. SUPPLEMENTARY NOTES	·	
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
Operating Characteristic Estimation Tailored Testing Latent Trait Theory		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
(Please see reverse side)		
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In the preceding research report, ONR/RR-82-1 (Information Loss Caused by Noise in Models for Dichotomous Items), observations were made on the effect of noise accommodated in different types of models on the dichotomous response level. In the present paper, focus is put upon the three-parameter logistic model, which is widely used among researchers. An emphasis is put upon the speed of convergence to the normality of the conditional distribution of the maximum likelihood estimate, given a specific ability level.

5/N 0102- LF- 014- 6601

## EFFECT OF NOISE IN THE THREE-PARAMETER

LOGISTIC MODEL

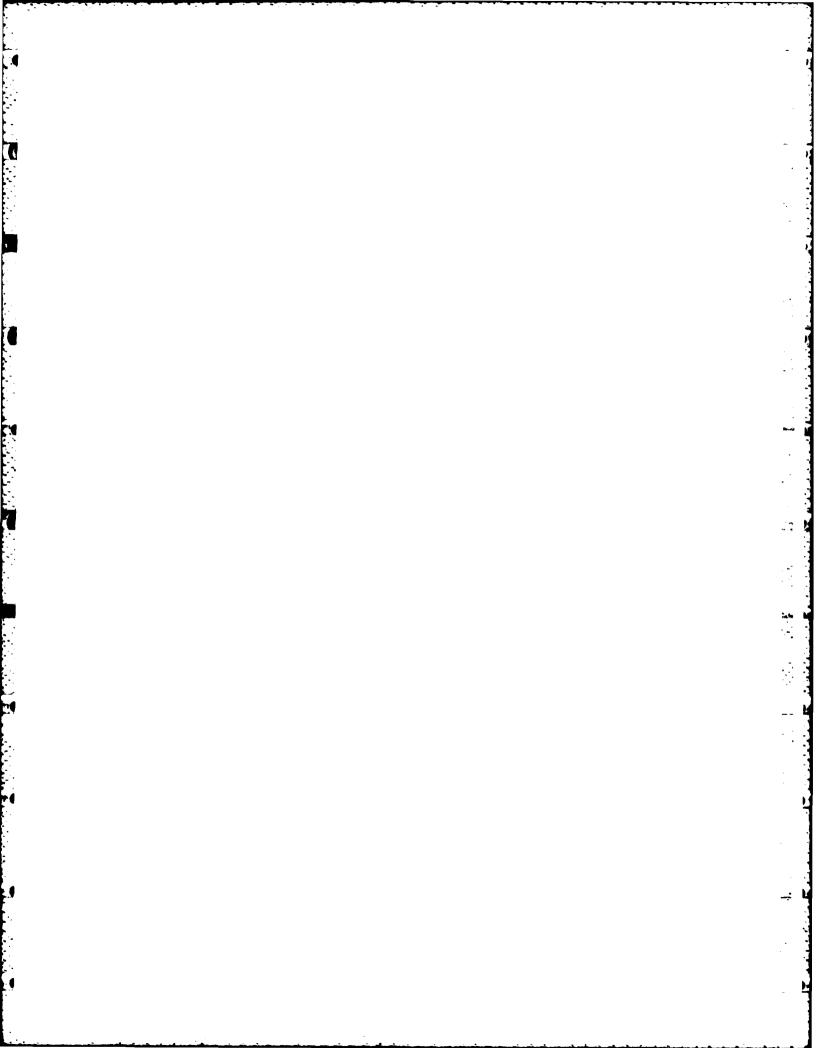
#### ABSTRACT

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### I Introduction

This is a continuation of the previous research report, which is entitled, "Information Loss Caused by Noise in Models for Dichotomous Items." In the present paper, we will focus our attention upon the three-parameter logistic model, which is widely used among researchers as a model for the multiple-choice test item in comparison with the normal ogive model.

Throughout this paper, we shall solely consider the unidimensional latent space. Let  $\theta$  denote the latent trait which assumes any real number. In dealing with the multiple-choice test item, there exist two distinct standpoints: 1) to treat the item as a dichotomous item, classifying the correct answer into one category and all the other alternative answers into the other, and 2) to treat it as a polychotomous item by acknowledging each alternative as an individual resource of information. In the former case, it is most common to define the binary item score,  $u_g$ , for item g and assign  $u_g = 1$  to the correct answer and  $u_o = 0$  to all the other alternative, incorrect answers. If we accept the knowledge or random guessing principle, i.e., that the examinee either knows the answer or guesses randomly, the three-parameter normal ogive, or logistic, model must be an appropriate model. An advantage of the model may be its simplicity. Two main disadvantages are, however, that: 1) in many practical situations, the knowledge or random guessing principle is not applicable, and 2) because of the noise caused by random guessing, we must do without certain mathematical properties which otherwise we could enjoy. If we take the second standpoint, we must

estimate the operating characteristic of each of the incorrect alternative answers, which sometimes are called distractors, in addition to the one for the correct answer. The operating characteristic of a distractor is called the <u>plausibility function</u>. A family of models for the multiple-choice test item, which takes both the characteristics of each distractor and noise caused by random guessing, has been proposed (Samejima, RR-79-4, Final Report).

In comparison with the first standpoint, there is no question that the second standpoint is better, in the sense that each test item will provide us with a greater amount of information, which leads to the more efficient estimation of the examinee's ability, or latent trait.

Although it requires more mathematical sophistication in dealing with it, it may be time that researchers switch to the second standpoint and enjoy its benefits. In estimating the plausibility functions of distractors, methods and approaches for estimating the operating characteristics of discrete item responses, such as Levine's (Levine, 1981) and Samejima's (Samejima, 1977a, RR-77-1, RR-78-1 to RR-78-6, RR-80-2, RR-80-4, RR-81-3, Final Report), will be useful. It has been found, amazingly, that many existing multiple-choice test items have informative distractors. In the future, however, it is desirable to modify the guidelines of test construction to encourage test developers to include more informative distractors, and to show how and with what principle they should do that.

At present, unfortunately, this second tide is yet to come.

Researchers use the three-parameter logistic model even if their data contradict the knowledge or random guessing principle. They claim that

the function can still be an approximation to the operating characteristic of the correct answer, regardless of the principle it may follow.

In the present paper, we will not question the adequacy of the three-parameter logistic model further than we already have. We will put ourselves in an assumption that, no matter what, we must use the three-parameter logistic model in a given situation. To begin with, we shall compare the three-parameter logistic model with the normal ogive model and find out, quantitatively, how much the three-parameter logistic model has to lose and, qualitatively, what kinds of deficiencies the model has because of the noise caused by random guessing.

# II General Characteristics of the Three-Parameter Logistic Model

Let  $P_g(\theta)$  be the operating characteristic of the correct answer to item g, or the item characteristic function. This function is the conditional probability, given  $\theta$ , with which the subject answers item g correctly. Since this conditional probability also equals the mean of the conditional distribution of the binary item score  $u_g$ , given  $\theta$ ,  $P_g(\theta)$  is also the regression of the binary item score  $u_g$  on ability  $\theta$ . Three-parameter logistic model is defined by the item characteristic function such that

(2.1) 
$$P_{g}(\theta) = c_{g} + (1-c_{g}) \Psi_{g}(\theta)$$
,

where  $c_g$  is a constant which equals the reciprocal of the number of the alternatives attached to the multiple-choice test item, which is called

the guessing parameter, and  $\Psi_{\mathbf{g}}(\theta)$  is given by

(2.2) 
$$\Psi_{g}(\theta) = [1 + \exp\{-Da_{g}(\theta - b_{g})\}]^{-1}$$
.

This function  $\psi_g(\theta)$  itself is the item characteristic function in the (two-parameter) logistic model. The two item parameters,  $a_g$  and  $b_g$ , in (2.2) are called the item discrimination parameter and the item difficulty parameter, respectively. The item discrimination parameter assumes any finite, positive value, and the item difficulty parameter takes on any finite, real number. The seemingly redundant constant, D, is a scaling factor, which adjusts the value of the discrimination parameter,  $a_g$ . When we set this scaling factor equal to 1.7, the same set of two item parameters,  $a_g$  and  $b_g$ , provides us with  $\psi_g(\theta)$  which is very close to the corresponding item characteristic function,  $\Psi_g(\theta)$ , in the normal ogive model (Birnbaum, 1968), which is defined by

(2.3) 
$$\phi_{g}(\theta) = (2\pi)^{-1/2} \int_{-\infty}^{a_{g}(\theta-b_{g})} e^{-u^{2}/2} du .$$

For this reason, the logistic model was originally developed as a substitute for the normal ogive model. The former provides us with a sufficient statistic, t(V), which is given by

(2.4) 
$$t(V) = \sum_{g=1}^{n} a_g u_g$$
,

for the response pattern,

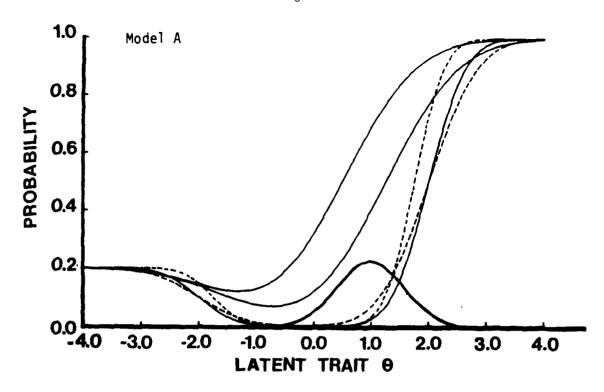
(2.5) 
$$V = (u_1, u_2, \dots, u_g, \dots, u_n)^{\dagger}$$
,

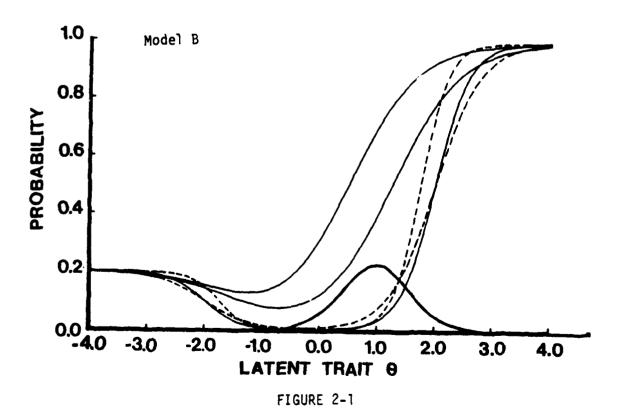
where n is the number of items in the test. The maximum likelihood estimate,  $\hat{\theta}_V$  . of ability  $\theta$  is given by the solution of

(2.6) 
$$t(V) = \sum_{g=1}^{n} a_g \Psi_g(\theta)$$

for the (two-parameter) logistic model.

It has been reported (e.g., Lord, 1968) that an unrestricted estimation of the three parameters in the three-parameter logistic model provides us with the estimated guessing parameter which is substantially different from the reciprocal of the number of the alternatives attached to the multiple-choice item, and very often the value is less. Note that this fact itself is an invalidation of the model. Many researchers stick to the model, however, as a simple numerical approximation to some unknown item characteristic function, which exists behind their empirical data and whose formula and rationale are hidden. For this reason, this third parameter  $c_{\mathbf{g}}$  is sometimes called pseudo-guessing parameter. This interpretation of the three-parameter logistic model casts some doubt, however. It has been shown (Samejima, RR-79-4; April 1980) that, if our test item follows a model in the new family of models for the multiplechoice test item, the operating characteristic of the correct answer, or item characteristic function, tends to have a non-monotonic form. Figure 2-1 presents several typical item characteristic functions in Models A, B





Typical Operating Characteristics of the Correct Answer in Models A, B and C. Ability Distribution of a Group of Hypothetical Examinees is Also Drawn by a Thick, Solid Line.

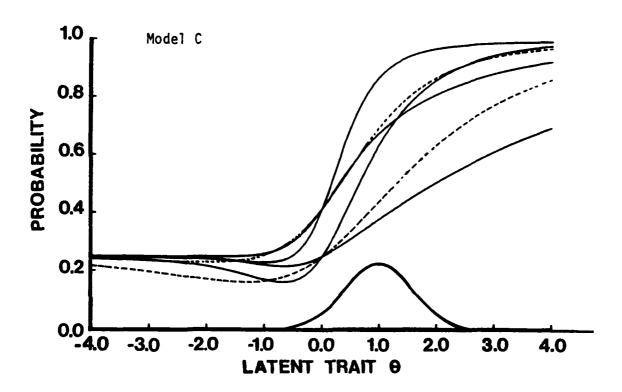


FIGURE 2-1 (Continued)

and C, respectively, which were taken from one of previous works (Samejima, RR-79-4). We can see in this figure that each operating characteristic of the correct answer decreases in  $\theta$  up to a certain level, and then starts increasing. If, for instance, our calibration data have been collected for a group of subjects whose ability distribution follows the density drawn by a thick, solid line in each graph of Figure 2-1, and if, nonetheless, we assume the three-parameter logistic model for our items, then the estimates of the parameters  $c_{\varrho}$ will be less than the reciprocal of the number of the alternatives. For the purpose of illustration, Figure 2-2 presents one of the curves of Model A with  $a_g = 1.00$ ,  $b_{x_g} = -1.50$ , -1.00, -0.50, 0.00, 0.50, which was taken from the first graph of Figure 2-1, by a solid line, and the item characteristic function in the three-parameter logistic model with  $a_g = 1.00$ ,  $b_g = 0.60$  and a pseudo-guessing parameter 0.05 by a dotted line. Comparison of these two curves in Figure 2-2 suggests that, for the interval of  $\theta$  where most of the subjects of our calibration data are located, these two item characteristic functions are practically identical. And yet the danger of accepting the three-parameter logistic model as the approximation for Model A is obvious, for the discrepancies are substantial outside this interval of  $\theta$ . If, for instance, the estimated item characteristic function in the three-parameter logistic model thus calibrated is applied for data collected for another group of subjects whose ability distribution is shifted to a lower side of  $\theta$ , then we will have a serious problem in analyzing our data because of these discrepancies. This fact also implies the danger of using a single set of

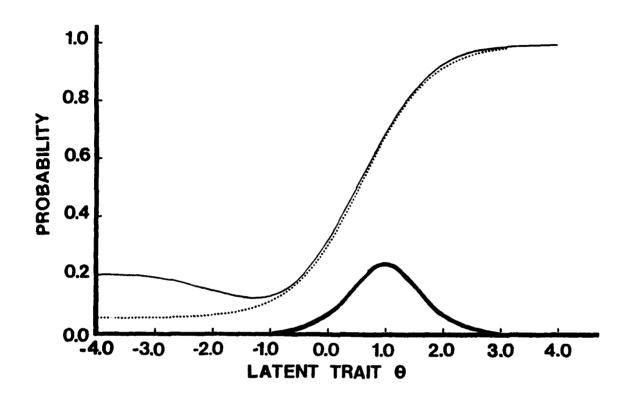


FIGURE 2-2

The Item Characteristic Function of an Item Following Model A with the Parameters  $a_g=1.00$ ,  $b_{\chi}=-1.50$ , -1.00, -0.50, 0.00 and 0.50 for  $\chi_g=1,2,3,4,5$  (Solid Line), and the One Following the Three-Parameter Logistic Model with  $a_g=1.00$ ,  $b_g=0.60$  and  $c_g=0.05$  (Dotted Line).

data in model validation. It should be kept in mind especially when our model fails to provide us with a sound rationale, as the three-parameter logistic model with a pseudo-guessing parameter does.

It has been pointed out (Samejima, 1972, 1973) that, unlike the (two-parameter) normal ogive and logistic models, the three-parameter logistic model does <u>not</u> provide us with a unique modal point for the likelihood function of every possible response pattern. We can write for the basic function (Samejima, 1969, 1972),  $A_{\rm ug}(\theta)$ , in the three-parameter logistic model,

(2.7) 
$$A_{u_g}^{(\theta)} \begin{cases} = -Da_g \Psi_g(\theta) & u_g = 0 \\ = [(1-c_g) Da_g \Psi_g(\theta) \{1-\Psi_g(\theta)\}] [c_g + (1-c_g) \Psi_g(\theta)]^{-1} & u_g = 1 \end{cases}$$

**::1** 

From (2.7) it is obvious that the basic function is not strictly decreasing in  $\theta$  for  $u_g$  = 1, although it is for  $u_g$  = 0. This leads to the fact that, while either in the normal ogive model or in the logistic model the item response information function (Samejima, 1972),  $I_{u_g}(\theta)$ , assumes positive values throughout the entire range of ability  $\theta$  for both  $u_g$  = 0 and  $u_g$  = 1, in the three-parameter logistic model there is an interval of  $\theta$  where  $I_{u_g}(\theta)$  assumes negative values for  $u_g$  = 1. This interval is  $(-\infty$ ,  $\theta_g)$ , where  $\theta_g$  is given by

(2.8) 
$$\theta_g = (2Da_g)^{-1} \log c_g + b_g$$

Several observations were made for the item response information function

in the three-parameter logistic model, which was used as an example of the Type B model (Samejima, ONR/RR-82-1).

# III Loss of Accuracy in Ability Estimation Caused by Random Guessing

In this section, we shall observe the loss of accuracy in estimating the examinee's ability caused by random guessing, by comparing the local standard errors of estimation of different hypothetical tests which follow the normal ogive model and the three-parameter logistic model with  $c_g = 0.20$  and  $c_g = 0.25$ , respectively. In so doing, we shall use hypothetical tests of equivalent items, or items having identical item characteristic functions. It was pointed out in the preceding section that the three-parameter logistic model does not assure a unique maximum for the likelihood function of every possible response pattern, and the item response information function for  $u_g = 1$  assumes negative values for the interval,  $(-\infty, \theta_g)$ . Thus it may be meaningless to discuss the standard error of estimation when single maximum likelihood estimates may not exist for some response patterns. If a test consists of equivalent items, however, a unique maximum likelihood estimate always exists for every response pattern, regardless of the model the items follow. In fact, the simple test score t, which is the sum total of the binary item scores, is a simple sufficient statistic for the response pattern V, and the maximum likelihood estimate,  $\theta_t$ , is obtained as the solution of

(3.1) 
$$(t/n) = P_{g}(\theta)$$
.

Note, however, that, if the item follows the three-parameter logistic model, or any other model of Type B, (3.1) will not have a solution if the relative test score, (t/n), is less than  $c_g$ . In such a case, the maximum likelihood estimate is negative infinity (cf. Samejima, ONR/RR-82-1).

In general, for a binary item  $\,g$  , the item response information function,  $\,I_{u_{_{\bm{0}}}}(\theta)$  , is defined by

(3.2) 
$$I_{u_g}(\theta) \begin{cases} = -\frac{\partial^2}{\partial \theta^2} \log Q_g(\theta) & u_g = 0 \\ = -\frac{\partial^2}{\partial \theta^2} \log P_g(\theta) & u_g = 1 \end{cases},$$

where  $P_g(\theta)$  and  $Q_g(\theta)$  [= 1- $P_g(\theta)$ ] are the operating characteristics of the correct and incorrect answers for item g, respectively. In the three-parameter logistic model,  $P_g(\theta)$  is given by (2.1) with (2.2) substituting for  $\Psi_g(\theta)$ , and, in the normal ogive model, it is replaced by the right hand side of (2.3). The item information function,  $I_g(\theta)$ , is the conditional expectation of the item response information function,  $I_{u_g}(\theta)$ , given  $\theta$ , and for a binary item g we obtain

(3.3) 
$$I_{\mathbf{g}}(\theta) = \mathbb{E}\left[I_{\mathbf{u}_{\mathbf{g}}}(\theta)|\theta\right] = \left[\frac{\partial}{\partial \theta}P_{\mathbf{g}}(\theta)\right]^{2} \left[P_{\mathbf{g}}(\theta)Q_{\mathbf{g}}(\theta)\right]^{-1}.$$

thas been shown (Samejima, RR-79-1, ONR/RR-82-1) that there exists some stancy for the amount of information given by a binary item, and, in particular, models of Type A which provide us with strictly increasing item characteristic functions with zero and unity as the two asymptotes, and to which the normal ogive model belongs, the area under the curve of

the square root of the item information function equals  $\pi$ . It has also been pointed out (Samejima, ONR/RR-82-1) that, for models of Type B, whose item characteristic functions are given by (2.1), and to which the three-parameter logistic model belongs, this area, Q, is given by

(3.4) 
$$Q = \pi - 2\tan^{-1}[c_g/(1-c_g)]^{1/2} .$$

When  $c_g = 0.20$ , Q equals, approximately,  $0.705\pi$ , and when  $c_g = 0.25$ , it is approximately  $0.667\pi$ .

When a test consists of only one item, the item information function  $I_g(\theta)$  equals the test information function  $I(\theta)$ , and the characteristics of the square root of the item information function apply directly for the square root of the item information function. In practice, however, it is a highly unlikely case, and there usually are more than one binary item in a test. The response pattern information function,  $I_V(\theta)$ , is defined by

(3.5) 
$$I_{V}(\theta) = -\frac{\partial^{2}}{\partial \theta^{2}} \log P_{V}(\theta) ,$$

where  $P_V(\theta)$  is the operating characteristic, or the conditional probability, given  $\theta$ , of the response pattern V. When the conditional independence of the item score distributions, given  $\theta$ , holds, this operating characteristic is given as the product of the operating characteristics of  $u_g$  which belong to the response pattern V. The test information function is defined as the conditional expectation of the

response pattern information function, given  $\,\,\theta\,$  , and thus we can write

(3.6) 
$$I(\theta) = E[I_{V}(\theta) | \theta] = \sum_{V} I(\theta) P_{V}(\theta) .$$

From (3.6), following through some mathematics, we obtain

(3.7) 
$$I(\theta) = \sum_{g=1}^{n} I_{g}(\theta) ,$$

provided that the conditional independence of the item score distribution holds.

We notice that, if the term under the summation on the right hand side of (3.7) were the square root of the item information function, instead of the item information function itself, then there would be a similar constancy for the amount of test information as there is for the amount of item information. As it is, however, there is no such constancy for the square root of the test information function, and, therefore, different combinations of items will provide us with different values for the area under the curve of the square root of the test information function.

When a test consists of n equivalent items, however, there exists a similar kind of constancy for the square root of the test information function, for from (3.7) we can write

(3.8) 
$$[I(\theta)]^{1/2} = n^{1/2} [I_g(\theta)]^{1/2}$$
,

1

where  $I_g(\theta)$  is the common item information function. This indicates that, when a test consists of n equivalent binary items following the normal ogive model, the area under the square root of the test information function equals  $n^{1/2}\pi$ , regardless of the common item parameters,  $a_{\sigma}$ and  $b_o$ , of those equivalent items. (3.8) also implies that, if a test has n equivalent binary items following the three-parameter logistic model with  $c_o = 0.20$ , then the area under the curve of the square root of the test information function approximately equals  $0.705~\text{n}^{1/2}\,\text{m}$  , and with  $c_g = 0.25$  it equals approximately  $0.667 \text{ n}^{1/2}\pi$ . Figure 3-1 illustrates the square roots of test information functions in the normal ogive model and in the three-parameter logistic model with  $c_g = 0.20$  and  $c_g = 0.25$  with the other common parameters  $a_g = 0.50$  and  $b_g = 0.00$ , by a dashed line and two solid lines, respectively, for n = 10, 20, 40,60, 80, 100, 120, 140, 160, 180, 200 . A similar comparison with respect to the three test information functions was made and is shown in Appendix, as Figure A-1.

We notice in those graphs of Figure 3-1 that the two curves for the three-parameter logistic model are much closer to each other, compared with their relationship with the curve for the normal ogive model. The values of  $\theta_g$ , which were obtained by (2.8), turned out to be -0.9467282900048181 and -0.8154673627399685 for  $c_g=0.20$  and  $c_g=0.25$ , respectively, and these values are also shown in Figure 3-1. It is observed that the distances between the curve for the normal ogive model and each of the two curves for the three-parameter logistic model are rapidly enhanced as  $\theta$  departs from  $\theta_g$  in the negative direction.

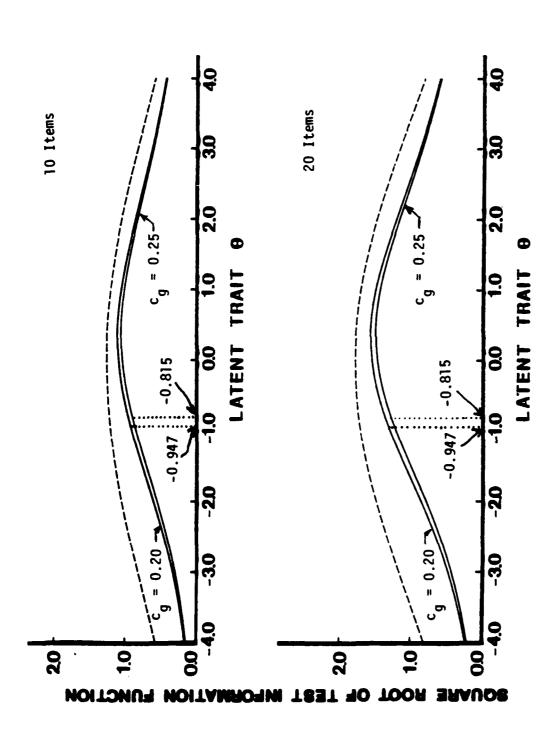
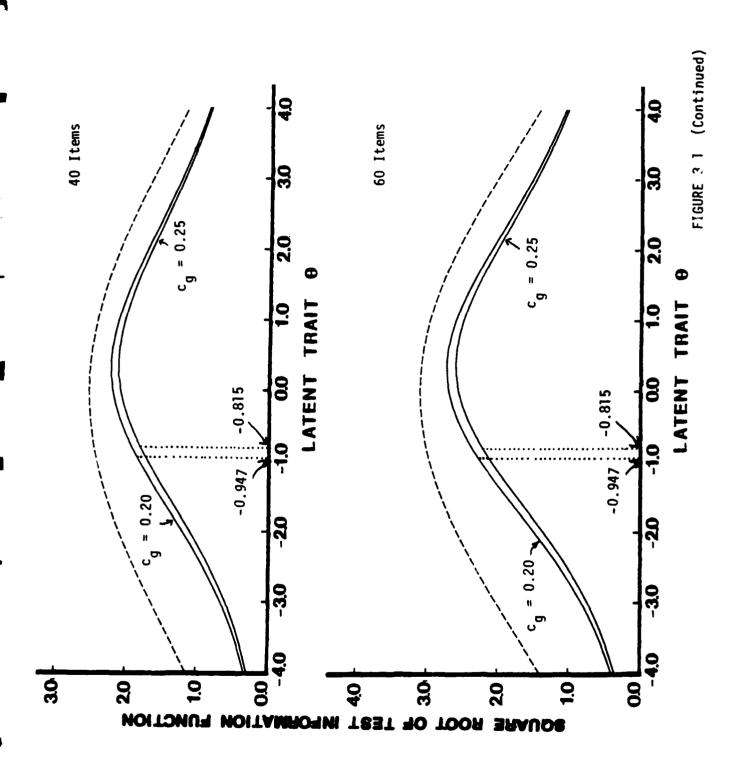


FIGURE 3-1

Square Roots of Test Information Functions of Each of Eleven Tests of Equivalent Items, in the Normal Ogive Model (Dashed Line), and in the Three-Parameter Logistic Model (Solid Lines) with  $c_{\rm J}=0.20$  and  $c_{\rm J}=0.25$ . The Two Are Shown. 6 Values of the Common

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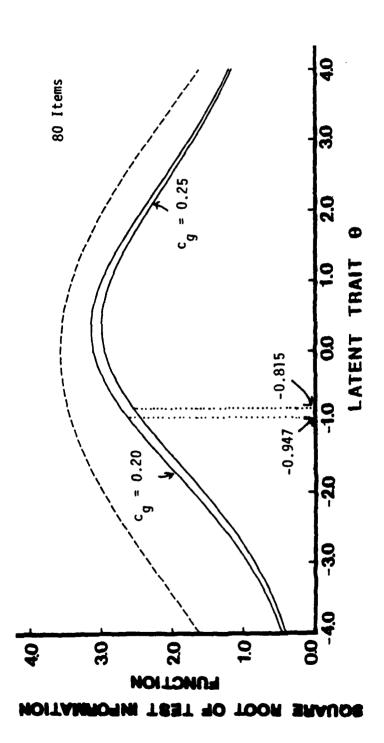


FIGURE 3-1 (Continued)

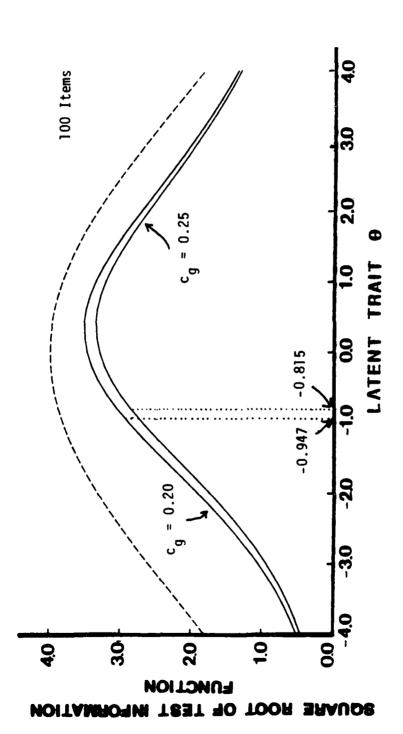


FIGURE 3-1 (Continued)

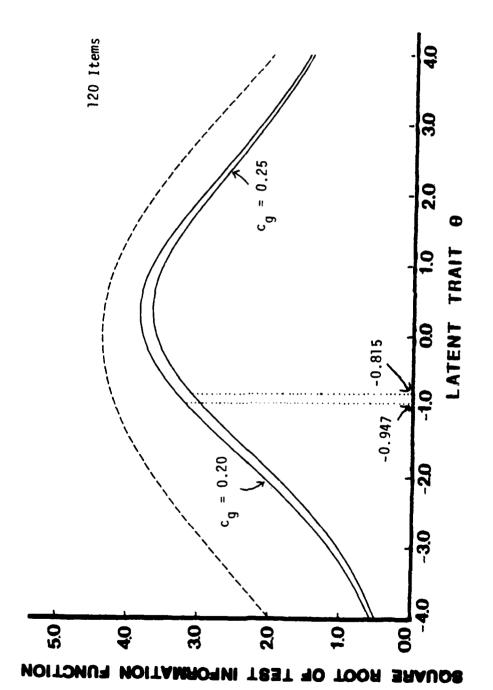


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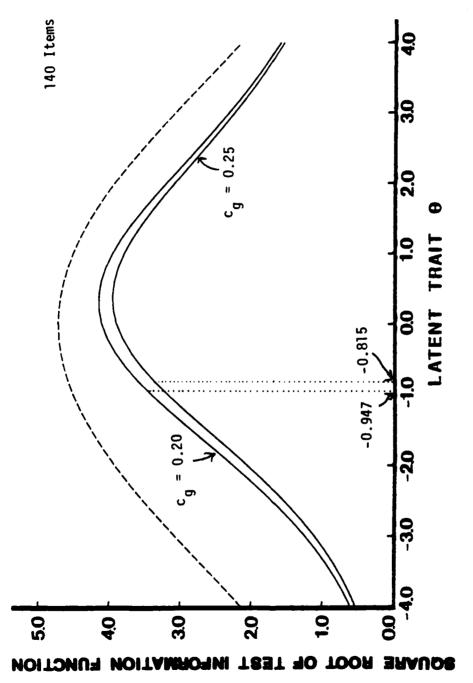


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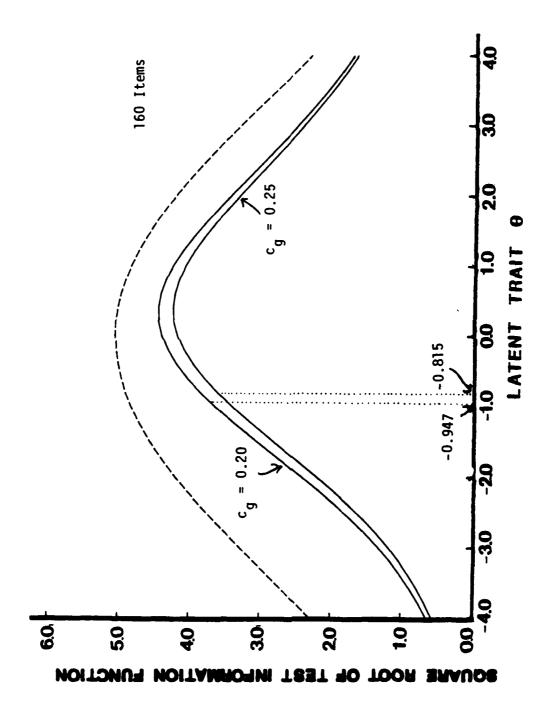


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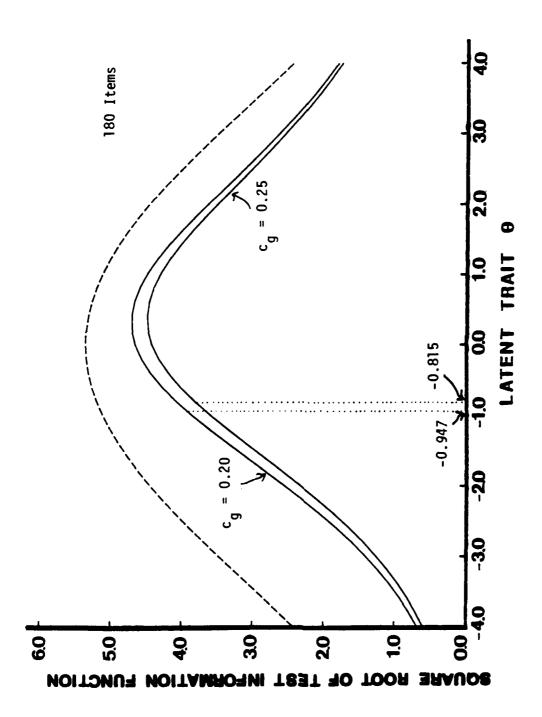


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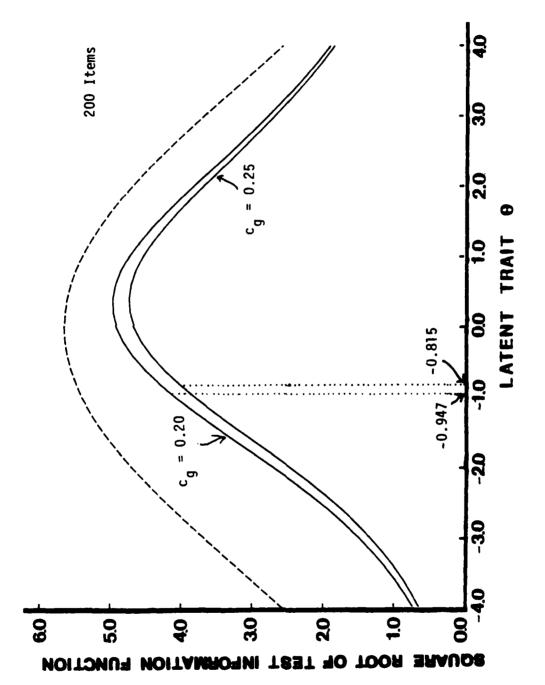
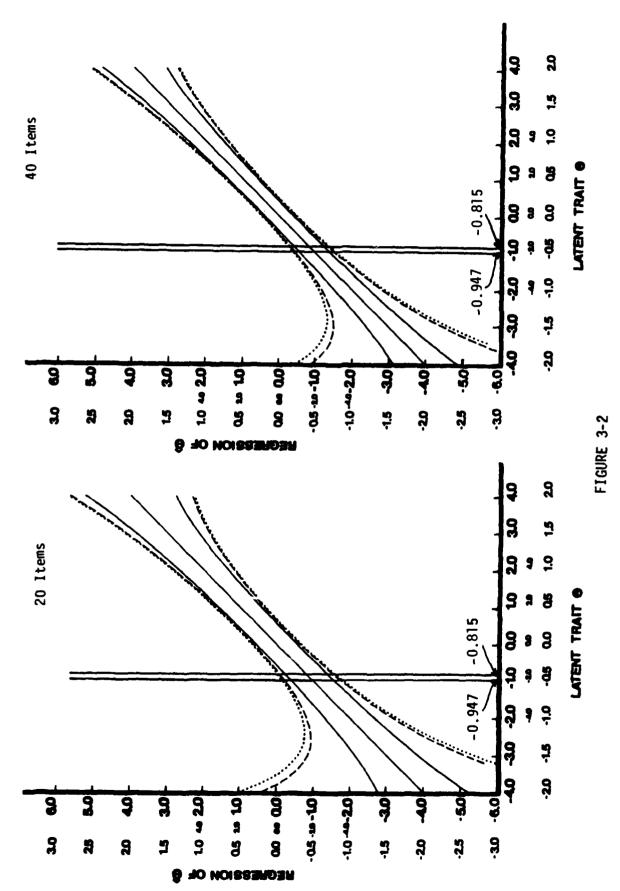


FIGURE 3-1 (Continued)

We notice that those graphs of three curves can be used for other sets of the parameters  $a_g$  and  $b_g$ , as long as we keep the values of  $c_g$  as they are. In so doing, we need to change the scale values shown on the abscissa and on the ordinate. If, for instance, we wish to use the graphs for  $a_g = 1.00$  instead of  $a_g = 0.50$  without changing the value of  $b_g$  (= 0.00), then we must change the numbers on the abscissa of Figure 3-1 to their half values, and also make those numbers on the ordinate twice as large as the original values. If we wish to use Figure A-1 in Appendix for the same purpose, then we will have to change the numbers on the abscissa in the same way as we did for Figure 3-1 and make the numbers on the ordinate four times as large as the original values.

By virtue of the asymptotic normality of the conditional distribution of the maximum likelihood estimate  $\hat{\theta}_V$ , given  $\theta$  (e.g., Kendall and Stuart, 1961, Samejima, 1975), the asymptotic regression of  $\hat{\theta}_V$  on  $\theta$  equals  $\theta$  itself, i.e., the maximum likelihood estimate V is asymptotically conditionally unbiased, and the conditional distribution is asymptotically normal with  $\theta$  and  $\left[I(\theta)\right]^{1/2}$  as its two parameters. It has been shown (Samejima, 1977a, 1977b, Final Report) that even for a relatively small number of items and a relatively small amount of test information this asymptotic property can be used as a good approximation to the conditional distribution of  $\hat{\theta}_V$ . Figure 3-2 presents the interval of  $\hat{\theta}_V$  which was obtained by using  $\theta$  as the regression of  $\hat{\theta}_V$  on  $\theta$  and  $\left[I(\theta)\right]^{1/2}$  as the standard error of estimation, which is plotted both above and below the regression line. In this figure, the two curves are drawn by solid lines for the normal ogive model, and they are drawn by



Standard Errors of Estimation Taken on Both Upper and Lower Sides of the "Unbiased" Regression of ê on e , in the Normal Ogive Model (Solid Line), in the Three-Parameter Logistic Model with c = 0.20 (Dashed Line) and with c = 0.25 (Dotted of Line), for Each of the Ten Tests of Equivalent Items. The Two Values of e g Are Also Shown.

7

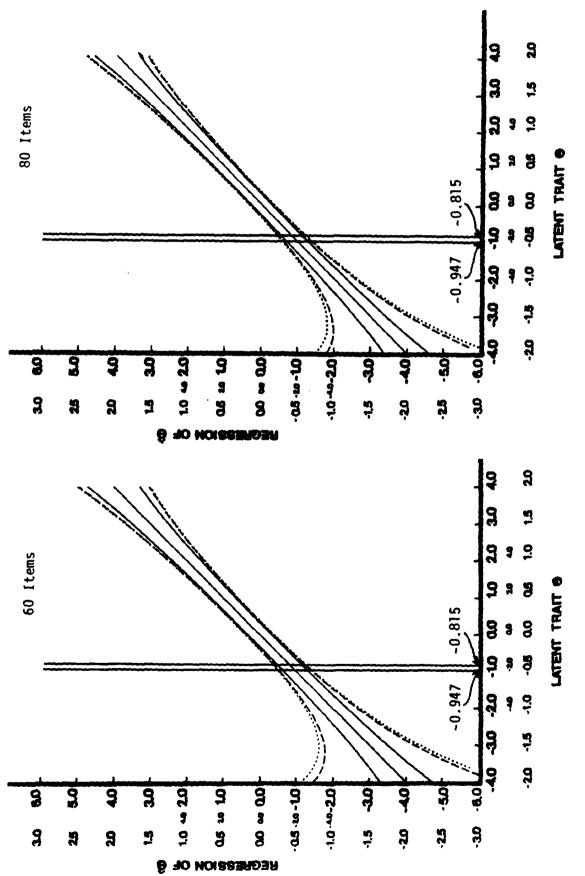


FIGURE 3-2 (Continued)

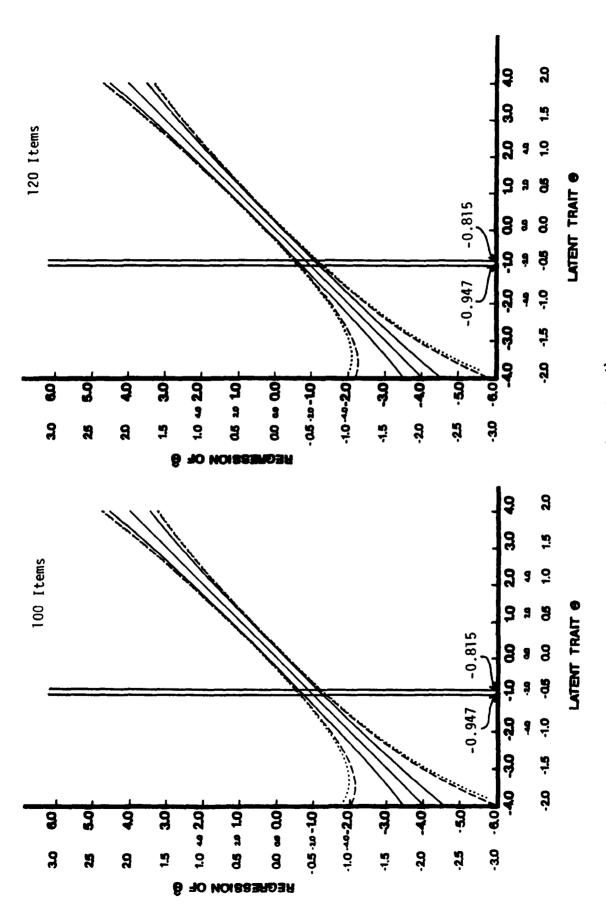


FIGURE 3-2 (Continued)

C

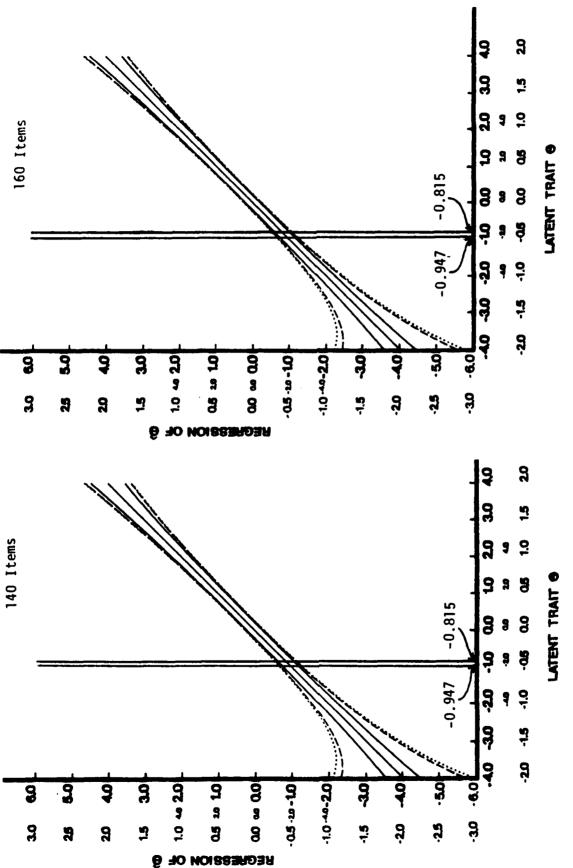


FIGURE 3-2 (Continued)

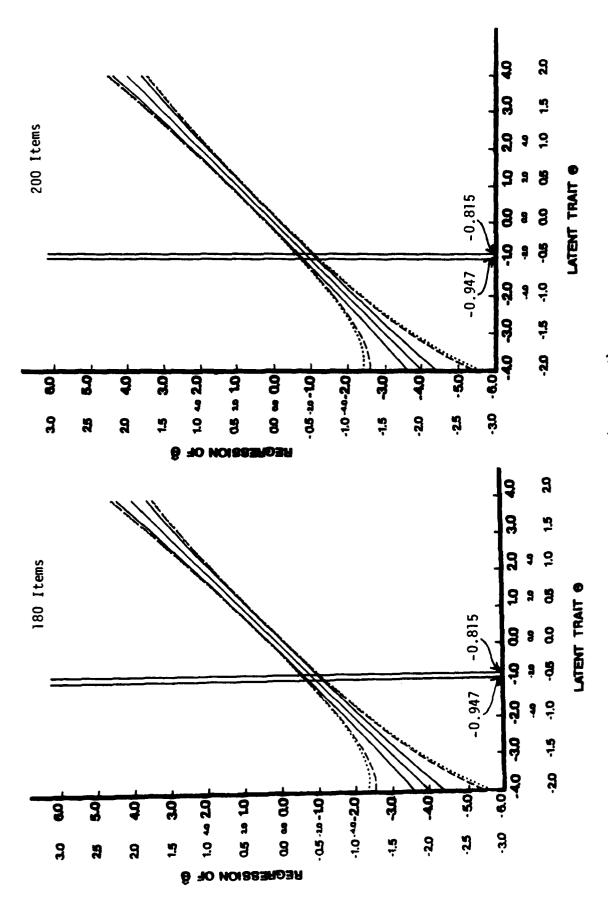


FIGURE 3-2 (Continued)

dashed and dotted lines for the three-parameter logistic model with  $c_g = 0.20$  and  $c_g = 0.25$ , respectively, for each of the ten tests of equivalent items. The number of items in those ten tests are 20, 40, 60, 80, 100, 120, 140, 160, 180 and 200, respectively. The common item parameters are the same as those used in the eleven tests in Figure 3-1, i.e.,  $a_g = 0.50$  and  $b_g = 0.00$ . On both the abscissa and the ordinate of Figure 3-2, two additional sets of numbers are shown in the smallest and medium sizes to adjust the scales to the change of  $a_g$  from 0.50 to 2.00 and 1.00, respectively.

We can see in these ten graphs of Figure 3-2 that for relatively large numbers of items the three-parameter logistic model provides us with reasonably small confidence intervals for certain intervals of  $\theta$ , but the accuracy of estimation drops radically as  $\theta$  departs from  $\theta_{\bf g}$  in the negative direction. Although this tendency is conspicuous for smaller numbers of items, it is still clear for larger numbers of items, like 200 . The effect of noise caused by random guessing is obvious, and we need to devise some way to make up for it if we must use the three-parameter logistic model.

## IV Loss in Speed of Convergence of the Conditional Distribution of the Maximum Likelihood Estimate to the Normality

In the preceding section, we have observed the loss of accuracy in ability estimation caused by random guessing, which is embedded in the three-parameter logistic model. In so doing, we compared the normal ogive model and the three-parameter logistic model with  $c_{\rm g}$  = 0.20 and  $c_{\rm g}$  = 0.25 , with respect to the confidence interval of the maximum

likelihood estimate  $\theta_t$ , given  $\theta$ , which was approximated by the unbiased regression and the reciprocal of the square root of the test information function as the standard error of estimation. Those confidence intervals are approximations, using the asymptotic normality of the maximum likelihood estimate, given  $\theta$ .

In this section, we shall focus our attention on the loss in the speed of convergence of the conditional distribution of the maximum likelihood estimate  $\hat{\theta}_t$  to the normality, which is caused by random guessing embedded in the three-parameter logistic model. In so doing, we shall use five hypothetical tests of equivalent items, i.e., n=20, 40, 80, 120, 200, which were chosen out of the ten tests used in the preceding section.

We notice that, with equivalent items, the conditional distribution of the test score t , given  $\theta$  , is binomial, with n and  $P_g(\theta)$  as the two parameters. Since there is one-to-one correspondence between the test score t and the maximum likelihood estimate  $\hat{\theta}_t$ , the probability function of t also applies to the probability function of  $\hat{\theta}_t$ , if each non-zero probability is assigned to  $\hat{\theta}_t$  instead of t. Questions are raised as to how close this discrete distribution is to  $N(\theta, \{I(\theta)\}^{-1/2})$ , and if there are substantial differences between the two models with respect to the speed of convergence to the normality.

We notice that in the normal ogive model  $\hat{\theta}_t$  assumes negative and positive infinities for t=0 and t=n, respectively, whereas in the three-parameter logistic model it does for  $t < nc_g$  and t=n. One measure of the speed of convergence to the normality, therefore, is the

probabilities assigned to the negative and positive infinities in each distribution, i.e., the greater these probabilities are, the slower the convergence to the normality is. Table 4-1 presents these probabilities assigned to the negative and positive infinities at each of the sixteen equally spaced points of  $\theta$  for each of the five hypothetical tests of equivalent items. We can see from this table that, in all five situations, where the numbers of items are 20, 40, 80, 120 and 200, respectively, the sum totals of the probabilities assigned to the negative or positive infinity on the three-parameter logistic model are substantially larger, compared with the ones on the normal ogive model.

Since the probabilities assigned to the negative and positive infinities are not zero in each conditional distribution of  $\hat{\theta}_t$ , given  $\theta$ , the moments of each distribution are indeterminate. As a crude measure, however, we shall compute the moments of each distribution by simply "ignoring" the negative and positive infinities and their corresponding probabilities. Tables 4-2 through 4-4 present the first moment about the origin and the second through fourth moments about the mean thus computed, for each of the sixteen values of  $\theta$ . For simplicity, the symbols  $\mu_1'$ ,  $\mu_2$ ,  $\mu_3$  and  $\mu_4$  are used for those moments, which indicate

(4.1) 
$$u_1^* = E(\hat{\theta}_1 | \theta)$$
,

and

TABLE 4-1

Sum Totals of Probabilities Assigned to Negative and Positive Infinities and Their Sum in the Conditional Distribution of  $\hat{\theta}_{f t}$ , given heta, at Sixteen Different Values of heta, on the Normal Ogive Model and on the

 $c_g$  = 0.25 . In all Three Cases, Items Are  $b_g$  = 0.00 . 20 Items. Three-Parameter Logistic Model with  $c_{g}$  = 0.20 and Equivalent with ag = 0.50 and

Nega	Negative Infinity	ty	Pos	Positive Infinity	ıty		Total	
Normal Ogive	3-P.L.	3-P.L.	Normal Ogive	$c_{g} = 0.20$	3-P.L. cg= 0.25	Normal Ogive	3-P.L.	3-P.L. cg 0.25
0.250858	0.383241	0.399937	0.000000	0.000000	0.000000	0.250858	0.383241	0.328158
0.054154	0.217702	0.244937	0.000000	0.000000	0.000000	0.054154	0.217702	0.244937
0.003925	0.064763	0.085083	0.000000	0.000000	0.000000	0.003925	0.064763	0.085083
0.000624	0.023528 0.005886	0.034868	0.0000000000000000000000000000000000000	0.000000	0.000000	0.000624	0.023528	0.034869
0.000004	0.000947	0.001973	0.000000	0.000011	0.000029	0.000005	0.000959	0.002002
0.000000	0.000000	0.000019	0.000066	0.000794	0.001348	0.000066	0.000800	0.001367
0.000000	0.000000	0.000000	0.003925	0.016070	0.021363	0.003925	0.016070	0.021363
0.000000	0.000000	0.000000	0.054154	0.104388	0.121155	0.054154	0.104388	0.121155
0.000000	0.000000	0.000000	0.250858	0.303082	0.327254	0.250858	0.303082	0.327254

Table 4-1 (Continued) 40 Items.

t

n

Negé	Negative Infinity	lty	Ров	Positive Infinity	ifty		Total		
Normal Ogive	3-P.L. cg 0.20	3-P.L.	Normal Ogive	3-P.L.	3-P.L.	Normal Ogive	3-P.L. cg 0.20	$a_{-}$ $a_{-}$ $b_{-}$ $b_{-}$ $c_{g}$ $a_{-}$ $a_{-}$ $a_{-}$ $a_{-}$	
0.062930	0.261408	0.288228	0.000000	0.000000	0.000000	0.062930	0.261408	0.288228	
0.002933	0.094627	C.121081	0.000000	0.000000	0.000000	0.002933	0.094627	0.121081	
0.000015	0.03/602	0.034863	0.0000000	0.0000000	0.0000000	0.000293	0.037602	0.054863	
0.000000	0.001358	0.003052	0.00000.0	00000000	0.00000.0	0.00000.0	0.001358	0.003052	
0.000000	060000.0	0.000278	0.00000.0	00000000	0.00000.0	000000.0	0.00000.0	0.000278	
00000000	0.000002	0.000011	0.00000.0	0.00000.0	00000000	000000.0	0.000002	0.000011	
0.000000	0.00000.0	000000000	00000000	00000000	00000000	00000000	0.00000.0	0.0000000	
0.000000	000000000	000000.0	0.00000.0	0.000001	0.000002	000000.0	0.000001	0.000002	
0.000000	0.00000.0	0.00000.0	0.00000.0	0.000017	0.000038	000000.0	0.000017	0.000038	
0.000000	0.00000.0	0.00000.0	0.000015	0.000258	0.000456	0.000015	0.000258	0.000456	
0.00000.0	0.00000.0	0.0000000	0.000293	0.002145	0.003242	0.000293	0.002145	0.003242	
0.00000.0	0.00000.0	0.00000	0.002933	0.010897	0.014679	0.002933	0.010897	0.014679	
0.000000	000000.0	000000000	0.017035	0.037050	0.045896	0.017035	0.037050	0.045896	
0.000000	0.000000	00000000	0.062930	0.091859	0.107095	0.062930	0.091859	0.107095	
-		_							-

Table 4-1 (Continued) 80 Items.

Negat	Negative Infinity	ty	Pos	Positive Infinity	ıfty		Total	
Normal Ogive	3-P.L.	$_{c_{g}}$ 0.25	Normal Ogive	$c_{g} = 0.20$	$_{\rm cg}^{\rm 3-P.L.}$	Normal Ogive	3-P.L.	3-P.L.
0.003960	0.144555	0.175542	0.000000	0.000000	0.000000	0.003960	0.144555	0.175542
0.00000.0	0.022414 0.003888	0.036598	0.0000000000000000000000000000000000000	0.000000	0.000000	0.0000000000000000000000000000000000000	0.022414	0.036598
0.000000	0.000279	0.000866	0.000000	0.000000	0.000000	0.000000	0.000279	0.000866
0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
0.0000000000000000000000000000000000000	0.000000	0.000000	0.000000	0.000000	0.00000	0.00000	0.000000	0.000000
0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.00000
0.000000	0.000000	0.000000	00000000	0.000005	0.000011	0.00000	0.000005	0.000011
0.000000	0.000000	0.000000	0.000290	0.001373	0.002106	0.000290	0.001373	0.002106

Table 4-1 (Continued) 120 Items.

		1													
	$^{3-P.L.}_{cg}$	0.114982	0.012206	0.001396	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.00000	0.000000	0.000003	0.000097	0.001228
Total	$^{3-P.L.}$ $^{c}g^{=}0.20$	0.086530	0.005892	0.000451	0.000000	0.000000	0.000000	0.000000	0.000000	0.00000.0	00000000	00000000	0.000001	0.000051	0.000775
	Normal Ogive	0.000249	0.000000	0.000000	0.000000	0.00000.0	0.00000.0	00000000	0.000000	00000000	0.00000.0	00000000	00000000	0.000005	0.000249
iity	3-P.L.	0.000000	0.000000	0.000000	0.000000	0.000000	0.00000.0	00000000	0.00000.0	000000.0	00000000	00000000	0.000003	0.000097	0.001228
Positive Infinity	$_{cg}$ 0.20	0.000000	0.000000	0.000000	0.000000	0.00000.0	00000000	00000000	00000000	0.00000.0	00000000	000000.0	0.000001	0.000051	0.000775
Poe	Normal Ogive	0.000000	0.000000	0.000000	0.000000	0.00000.0	0.00000.0	0.0000000	0.0000000	0.00000.0	0.00000.0	0.00000.0	0.00000.0	0.000005	0.000249
l ty	3-P.L.	0.114982	0.012206	0.001396	0.000000	00000000	000000.0	0.00000.0	0.00000.0	0.0000000	0.00000.0	00000000	000000.0	0.00000.0	0.000000
Negative Infinity	3-P.L. cg 0.20	0.086530	0.005892	0.000451	0.000000	00000000	0.000000	0.00000.0	00000000	0.0000000	0.00000.0	00000000	00000000	0.0000000	0.000000
Nega	Normal Ogive	0.000249	0.000000	0.000000	0.000000	0.0000000	0.000000	0.000000	00000000	0.00000.0	0.000000	0.000000	000000.0	000000000	0.0000000

Table 4-1 (Continued) 200 Items.

	3-P.1.	0.053680	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000014
Total	3-P.L.	0.033982	0.000007	0.000000	0.000000	0.000000	0.000000	0.000000	0.000007
	Normal Ogive	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000001
ity	$_{\rm cg}^{3-\rm P.L.}$	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000014
Positive Infinity	$_{c_{g}}^{3-P.L.}$	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000007
Pos	Normal Ogive	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000001
ty	$_{cg}^{3-p.L.}$	0.053680	0.000045	0.000000	0.000000	0.000000	0.000000	0.000000	0.0000000
Negative Infinity	$_{c_{g}}^{3-p.L.}$	0.033982	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Nega	Normal Ogive	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

## Table 4-2

Type of Distribution obtained at Sixteen Different Values of 0 , for Each of the Five Hypothetical Tests of Equivalent Items on the Mormal Cylve Morel with a 3 0.50 and b = 0.00 . Moments Were Calculated by "Ignoring" Negative and Positive Infinities.

The Mark \*\* Todicites that the Sum Jotal of the Probabilities for Finite Values of 6 to Is Greater Than, or Equal to, 0.99 and Less Than 0.999999 . 20 Items. Conditional Mean of Second to Fourth Moments, uz, ug and ug, Indices 81 and 82, Pearson's Criterion K and Pearson's

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Table 4-2 (Continued) 40 Items.

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ע	01 -0.2870568533D 00	0.37053220C0D 01	0.271874690AD 00	0.14807355670 00	0.90414077780-01	0.38729290980-01	0.4714925698D-02	0.47149256980-02	0.38729290980-01	0.90414077780-01	0.14807355670 00	0.2718746904D 00	0.3705322090D 01	-0.2824465317D 00	-0.28705685330 00
2 ع	0.2c34047577D 01 -0.2870568533D		0.37040347110 61	0.35944131510 01	0.3282974546D 01	0.31750414570 01	0.31319377650 01	0.3131937765D 01	0.3175041457D 01	0.32829745460 01	0.3494413151D 01	0.37040347110 01	0.3523141209D 01	0.30108508550 01	0.26540475770 01
es.	0.1017066432D 01	0.32504686270 00	0.2374378795D 00	0.12015719175 00	0.49612807515-01	0.15592221840-01	0.16265025670-02	0.16268025670-02	0.1559222184 p-01	0.49612807519-01	0.12015719170 90	0.23743787950 00	0.3250468627D 00	0.3948421600D 00	0.1017066432D 01
TI.	0.28406971100 00	0.28864169350 00	0.21498977210 00	0.14771726460 00	0.11027668990 00	0.9216792240D-01	0.84690612680-01	0.84690612680-01	0.9215792240D-01	0.11027568990 00	0; 7171726460 00	0.21498977210 00	0.2886416935D 00	0.30376247590 00	0.2840697110b 00
z.	0.3271584280D 00 -0.1887173500D 00	58D 00 -0.8730613238D-01	97p 00 -0.5752116916p-01	290 00[-0.32316002960-01]	00 -0.17476584910-01	-0.8781563686D-02	-0.2689577344D-02	0.2689577344D-02	0.87816636860-02	0.17476684910-01	0.32316002960-01	0.57621169160-01	0.87306132380-01	0.1124852092D 00	0.1887173500b 00
<b>7</b> n	0.32715842800 00	0.28622957580 00	0.24091917970 00	C.2056025529D 90	9.1832770572D 00	0.170378660ZD 00	C.1614413659th 00	0.16444136590 00	0.1703786602D CO	0.18327705729 00	0.20560255299 00	0.24091917970 00		0.31753067720 00	0.32715642800 00
7.	-0.28528389630 01 -0.26346151300 01	-0.22660761490 01	-0.1852545573D 01	-0.1435964279D 01	-0.1023107961B 01	-0.61294075150 00	-0.2041702951E OC	0.2041702951D (C)	0.61294075150 00	0.10231079610 01	0.14359642790 01	0.18525455730 01	0.22660761490 01	0.26346151300 01	0.28528389630 01
٠	3.0	-2.2	-1.8	4	0	و. ب	4.2	0.5	9.0	6.	<b>4</b>	<b>*</b>	2.2	5.6	0.0
		~	4	^	۵	<b>p</b> ,	•¢	•	2	=	12	1	•	2	2

Table 4-2 (Continued) 80 Items.

	*	*	*	ţ	*	*	*	*	ŧ	‡	ţ	*	:	•		
type	_	4	4	4	4	4	4	4	4	4	~	4	*	4	-	
¥	0.3604885556D 01 -0.1958798807D 01	0.38273617520 00	0.22693428450 00	0.1894274502D 00	0.14425414650 00	0.88526386660-01	0.36494476030-01	0.4362715499D-02	0.43627154990-02	0.36494476030-01	0.88526386560-01	0.14425414550 00	0.18942745020 (10	C.2269342845D 00	0.3827361752D 00	-0.19587988070 01
8 2	0.3604885556D 01	0.3897385072D 01	0.3599956124D 01	0.3321539842D 01	0.3183498898D 01	0.31128327890 01	0.3075928320D 01	0.3059865604D 01	0.305986560AD 01	0.3075928320b cl	U.3112832789D 01	0.3183498898D 01	0.33215398420 01	0.3599956124 D 01	0.38973850720 01	0.36048855569 01
<b>8</b>	0.4703640826D 00	0.3493813866D 00	0.1855591492D 00	0.91178017210-01	0.44437213890-01	0.19597286540-01	0.64382637410-02	0.634 34 68 684 11-03	0.6843468684 0-03	0.64382637410-02	3.195972R654D-01	0.44437213890-01	0.91178017210-01	0.1853591492b 00	0.3493813866D 00	0.4703640826D 00
A A	0.17178759980 00	0.11470301960 00	0.66077838820-01	0.4209580870D-01	0.30553075410-01	0.24459820990-01	0.21226726190-01	0.1980747426D-01	0.19807474260-01	0.21226726190-01	0.244 5982099 D-01	0,30553075410-01	0.4 209 58087 0D-01	0.6607783882D-01	0.11470301960 00	0.17178759980 00
۴3	D 00 -0.6995074161D-01	00 -0.42000168460-01	00 -0.21481279860-01	D 00(-0.1140563883D-01	10-01 -0.6463772790D-02	D-01 -0.3694631109D-02	1D-01  -0.1921164208D-02	D-01 -0.5970i21964 D-03	0.5970121964 D-03	0.1921164 2080-02	0.36946311090-02	0.6463772790D-02	0.11405638830-01	0.2148127986D-01	0.42000168460-01	0.69950741610-01
и2	0.2182982052D 00	0.17155396770 00	0.1354812863D 00	0.11257700630 00	0.97965940920-01	9.8864387669D-01	0.83071758430-01	0.804569146415-01	0.8045691464 0-01	0.83071758430-01	0.88643876652-01	0.97965940920-01	9.1125770063P 00	0.13548128630 00	0.17155396770 00	0.2182982052D 00
<sup>I</sup> n	-3.0 -0.3061450503D 01	-2.6  -0.2652758925D 01	-0.2236642725D 01	-0.18252036749 01	-0.1417158971D 01	-0.1011126440D 01	-0.6062573162D 00	-0.2020249305p 00	0.20202493050 00	0.6062673162D 00	0.10111264400 01	0.14171589715 01	0.1825203674D 91	0.22366427259 01	0.2652758925D 01	0.3061450503D 01
θ	-3.0	-2.6	-2.2	a: 1-	4:1-	0.1-	9.0	7.0	0.3	9.0	0.1	₹.	8.1	2.2	9.2	3.0
	-	7	~	4	v	9	^	<b>6</b> 0	6	٠ <u>٠</u>	=	12	2	14	12	ų

Table 4-2 (Continued) 120 Items.

	*	-	-	4	÷	-	፥	<u>:</u>	<u>:</u>	<u>:</u>	:	:	:	*	*	<u>+</u>
Eype	-	-	-4	<u></u>	-			4	-	-	_	-		۵.	7	-
צ	0.40861850730 00	0.25472737300 00	0.23162951430 99	6.19586743070 00	0.1447851771D 00	0.87514857380-01	0.35772777160-01	0.425837.08760-02	0.42588709760-02	0.3577277165-01	0.87514857380-01	0.14478517710 00	0.19595743670 (0	0.23162051430 00	0.25472737300 00	0.40861850730 90
æ.	0.15 57 0108810 01	0.2574 17984 0D 01	0.3326195852B 01	0.31351131315 01	C.31116747/90 01	0.3070841395n 01	0.30486263500 01	0.30387674985 01	0.3038767498n 01	0.304862605cb 01	0.3070941395D 01	0.31116747790 01	0.31851131310 01	0.33261938520 01	0.362417984GD Of	0.3987010881b of
B	9.3930473212D 00	9.2045810348D 00	0.1031611277 0.00	0.5379845239D-01	0.27164724190-01	0.12217411980-01	0.40542061140-021	0.43284425260-03	0.4 3284 3 25260-03	0.4 354 2061 14 15-02	0.12217411980-01	0.271347241915-01	0.53798452399-01	0.10316112770 00	0.20458103480 00	0.39304732125 00
LA.	0.82113663610-01	0.4 291532781B-01	0.25328184250-01	0.17186799770-01	0.12899281520-01	0.10507809372-01	0.92027700709-02	0.86219390941-02	0.8621939094 D-02	0.9202770070b-02	0.10307809370-01	C.1239928152D-01	0.1718675977L-01	0.25328184250-01	0.4291532781D-01	0.82113663610-01
μ <sub>3</sub>	190 co -0.34083832830-01	22D 00 -0.1623621173D-01	15D-01  -0.8279425830D-02	650-01 -0.46178253930-02	2420-01 (-0.26936487080-02)	566D-01 (-0.1563798199D-02)	010-01 -0.81999975660-03	-0.2557681346D-03	0.25576813460-03	0.81999975661-03	0.15637981990-02	0.26936487080-02	0.46179253930-02	0.82794258300-02	0.16236211735-01	0.34083832830-01
<sup>n</sup> 2	0.14351060790 00	0.1088181522D 00	0.87262594150-01	0.73457319650-01	0.64385142420-01	0.58496165660-01	0.54942347010-01	0.53266448190-01	0.5326644819D-01	0.54942347010-01	n.5849616566D-01	0.64385142420-01	0.73457319650-01	0.87262594150-01	0.1086181522D 00	0.143513607910 00
2	-3.0  -0.3050562378D 01	-2.6 -0.2634604929D 01	-0.2223774113D 01	-0.1816478924D 01 {	-0.1411274629D 01	-0.1007331922p 01	-0.6041366202D 00	-0.2013374948D CO	0.20133749480 00	0.60413662020 00	0.1007331922D 01	0.1411274629D 01	0.18164789240 01	0.22237741130 01	0.26346049290 01	0.30505623780 01
Ø	-3.0	-2.6	-2.2	ec		0.1	\$.0	9	0.2	3.0	ن.	4		1.1	5.6	0,8
		۲,	•	٠,٠	·	-	_	•	•	:2	=	<u>.</u>	:3	£	2	91

Table 4-2 (Continued) 200 Items.

	<del>,                                    </del>	_	· ×	+	*	-		÷	*		¥	<u>.</u>				*
type	4	~	-	4	_	~	*	*	4	-4	.4	_	*	*	4	
¥	0.2793135304D 00	0.27107579290 00	0.24243721260 00	0.1986177437D 00	0.1446129416D 00	0.86629254380-01	5.3521069409D-01	0 11798947440-02	3.3179334744D-02	0.3521069409D-0.	0.46623256380-01	0.14151294160 00	0.19261774370 00	0.2624372125D 00	0.2710757929B G	0.27931353040 00
8 2	0.3565765502D 01	0.32930521600 01	0.316/5506810 01	0.3100889668D G1	0.30628337690 01	0.30406657900 0	0.3028305234p 0il	C. 30227476580 01	0.3022747658D 01	0.30283052340 01	0.30406697939 06	C.3062833769D 01	0.31008846680 Oil	0.31675506810 01	0.32930521600 01	0.3565/65502D 01
8	0.19440201660 00	0.10040066320 00	0.5460858031D-01	0.23654169000-01	0.15313473630-01	0.59682513505-02	0.232839 10330-02	0.34936590110-03	0.24936590110-03	0.23283530300-02	9.69682513:00:-02	C.1531.34736319-04	0.29554169005-91	0.34508580310-01	0.10000066320 co	0.19440231660 00
2	0.2329419244 D-01	0.12940957240-01	0.82653480740-02	0.5834803632D-02	0.44724582090-02	0.36868853905-02	0.1250172674 D-02	0.10539442350-02	0.3053944236D-02	0.32501726740-02	0.3686883390R-C2	0.64726532690-02	0.58348036320-02	9.8265368034 pH02	0.1230C95728 D-01	0.1129619244 0-01
36	C. 8082532136P-01 -0.1013144854 D-01	0.62687925220-01 [-0.49732940160-02]	3.51082105250-01 -0.26979483080-02	1.4327804404 P-01 -0.1555778721 P-02	1.38213026212-01   -0.924337500-03	5700-01 - 0.5424124976U-03	132750711570-01[-0.28612660160-03]	0.85-01 (-0.8948/616400-04)	C.894 E7 61 C4 OD-04	9.18512660160-03(	0.3524 33-37819-03	6192438717606 63				6.16131448540-01
<b>2</b> <sub>n</sub>		u	·		9.38213026212-01	9.348213387cb-01	-	0.317A5SA	2,217,85%		J. 34821316/ JV-Cl	0.1806630000000000000000000000000000000000	6.4 337874404 D-01	3,5109210	1.4.553/92.1229-01	C. 31296216527 01 0.85825321360-01
-3	-3.0 -0.30296216520 01	-2.6 (-0.2675144614D 01	-2.2 -0.221397 X417 011	-1.8 1.0.1809744615p 01	11.4 1-0.14 0663000 \$ 01	1.0 -0.10043595875 01	-0.6074526540 DA	Jan 41.593901005 (m)	6 75977669278 001	6 50245266'45. ··· (	0. 10435368 C.	9,1806630	0.18,9744. 391. 1.	1 1 1 2 1 1 2 1 1 2 2 1 1 1 2 2 1 1 1 1	6.25/61345130	C. 34296216521 01
•	-3.0	9.7	-2.2	*C	<b>4</b> .	0	9		:	<u>د</u> ،	ζ	4	•	~:	0	<u>ې</u>
						-		_	_						4.4	

Table 4-3

Conditional Mean  $\mu_1^i$  , Second to Fourth Moments,  $\mu_2^i$  ,  $\mu_3^i$  and  $\mu_4^i$  , Indices  $\beta_1^i$  and  $\beta_2^i$  , Pearson's Criterion  $\kappa^i$  and Pearson's Type of Distribution Obtained at Sixteen Different Values of 0, for Each of the Five Hypothetical Tests of Equivalent Items on the Three-Parameter Logistic Model with a = 0.50, b = 0.00 and c = 0.20. Moments Were Calculated by "Ignoring" Negative and Positive Infinities. The Mark \*\* Indicates That the Sum Total of the Probabilities for Finite Values of a Is Greater Than, or Equal to, 0.99 and Less Than 0.99999, and \*\* Means It Is Greater Than, or Equal to, 0.99 and Less Than

							*	*	*	*	*					
£Abe		_	_	_	_	_	4	<u> </u>	4	_	<u> </u>		<u> </u>	_	_	_
¥	0.3246621439D 01 -0.8007813812D 00	0.3185364971D 01 -0.6486301059D 00	-0.4579758368D 00	-0.32992142390 00	-0.3220750870D 00	01  -0.1206387508D 01	0.25431705960 00	0.4408288923D-01	0.15079757060-03	0.577720457910-01	0.4097690286D 00	-0.3128111028D 00	00 003835200 00	-0.2061911385D 00	1.2357784501D 01 -0.4111824870D 00	0.2323052368D 01 -0.6972623065D 00
8 2	0.3246621439D 01	0.3185364971D 01	0.3090836415D 01 -0.4579758368D	0.3010012224D 01 -0.3299214239D	0.3087257559D 01 -0.3220750870D	0.3416948553D 01	0.38480883700 01	0.3988577851D 01	0.3873242545D 01	0.37891254460 01	0.3529829050D 01	0.30540764660 01	0.2646366255D 01	0.2429501476D 01 -0.2061911385D	0.23577845010 01	0.23230523680 01
β 1	0.2893742252D 01	0.2524375606D 01	0.1792293305D 01	0.95069791220 00	0.49045284210 00	0.3590894017D 00	0.27514253520 00	0.95613463910-01	0.34525810980-03	0.96145996310-01	0.2149151657D 00	0.2388650830D 00	0.2939568362D 00	0.6853155121D 00	0.1611528430D 01	0.2163420685D 01
n.	0.22799421560 01	0.1797881015B 01	0.1482905472D 01	0.1404816156D 01	0.1493023963D 01	0.1541719644D 01	0.1380994156D 01	0.1090982988D 01	0.91704425410 00	0.93912410980 00	0.1026344758D 01	0.1006011192D 01	0.84907580610 00	0.68678566710 00	0.7238524079D 00	0.11794144880 01
n 3	35p 00 -0.1304965575p 01	-0.1034613873D 01	10 -0.7717606421D 00	00 -0.55056638960 00	00 -0.40613373450 00	00 -0.3298955964 D 00	00 -0.24321422390 00	-0.1169524853D 00	0.6306793983D-02	0.1089189904D 00	0.1835643024D 00	0.21250468750 00	0.2311341778b 00	0.32093961180 00	0.52357442190 00	0.88465937170 00
۲,	0.8380039935D 00	0.75127834920 00 -0.10346138730	0.69265779130 00	0.6831650135D 00	0.69541964970 00	0.6717125818D 00	0.5990642482D 00	0.5229979092D 00	0.4865839731D 00	0.49784253950 00	0.53922472510 00	0.57393333890 00	0.56643262300 00	0.53168208610 00	0.55408061650 00	0.71253094300 00
*a**	3.0 -0.1380745760D 01	-2.6 -0.1473213007B 01	-0.1528935763D 01	-0.1499269840D 01	-0.1339246182D 01	-0.1041668878D 01	-0.6492371601D 00	-0.2193070231D 00	0.21608742340 00	0.64987991630 00	0.1077110256D 01	0.14745169620 01	0.17928747990 01	0.19750057660 01	0.1990866714D 01	0.18565599440 01
Φ	-3.0	-2.6	-2.2		4:1-	_	9.9	7.9	0.7	9:0	1:0	1.4	1.8	2.2	2.6	3.0
	_	~	•	4	•	•	^	20	•	2	=	13	13	*	15	16
	_	_	_	_	_	_	_	-	_		_	_		_	_	_

Table 4-3 (Continued) 40 Items.

	, -	_	_	_	*	*	*	*	¥	<u>.</u>	*	*	*	_	_	
Sqv3	_	· <del>-</del>	_	_	9	<u> </u>	4	4	*	4	4	4	9	_	_	_
<b>u</b>	0.3315396994 D 01 -0.7760817329 D	01 -0.6136218938D 00	-0.50602518760 00	-0.7100935759D 00	0.3334722687D 01	0.35037325510 00	0.12356119240 00	0.3423139934D-01	0.1911230286D-03	0.4310691873D-01	0.12828892430 00	0.2789693332D 00	0.1126837774D 01	-0.5764762882D 00	-0.2628767387D 00	-0.3269885102D 00
2 8	0.3515396994D 01	0.35941376520 01	0.36146597010 01	0.38604830050 01	0.4460708690D 01	0.4759606106D 01	0.4136271163D 01	0.3509612712D 01	0.33317464300 01	0.3430804821D 01	0.3766592139D 01	0.4152325468D 01	0.4038326621D 01	0.3416019130D 01	0.28621340630 01	0.2599867694D 01 -0.3269885102D
B <sub>1</sub>	0.2968942265D 01	0.2442861654D 01	0.1567919506D OI	0.1039657236D 01	0.89199914390 00	0.6387900781D 00	0.2389677362D 00	0.40386586290-01	0.1684793707D-03	0.4174868499D-01	0.16798097620 00	0.3862263382D 00	0.55256662090 00	0.5494671561D 00	0.6405686595D 00	0.1266147474D 01
д <b>ч</b>	0.2761481570D 01	0.2023146265D 01	0.1648642003D 01	0.1446543281D 01	0.11257061930 01	0.66473621320 00	0.3302287040D 00	0.19659380200 00	0.1623264734D 00	0.17553242270 00	0.24054904980 00	0,38532768230 00	0.5860594302D 00	0.7116711176D 00	0.69544432990 00	0.6797516327b 00
u <sub>3</sub>	1130 00 -0.14377279150 01	0 -0.1015719681D 01	-0.6950172763D 00	-0.4883289042D 00	-0.3362777351D 00	-0.1825945561D 00	-0.7342162599B-01	-0.23139370680-01	0.13460507210-02	0.2198074469D-01	0.52068052970-01	0.10449007970 00	0.1747823144D 00	0.2285810135p 00	0.2769887574D 00	0.4114256894D 00
"2	0.8863064013D 00	0.75026776530 00	0.67539184500 00	0.61213173270 00	0.50235484670 00	0.37371362380 00	0.2825549428D 00	0.2366765956D 00	0.22072864960 00	0.2261937649D 00	0.25271296610 00	0.3046277141D 00	0.38095186870 00	0.45643561390 00	0.4929310769D 00	0.5113279187D 00
- <u>a</u> -	-0.1979041597b 01	-0.2054962301D 01	-0.2019189471D 01	-0.1821885421D 01	-0.1477247203D 01	-0.1059309762D 01	-0.6307806842D 00	-0.2092595422D 00	0.20768741250 00	0.6239177526D 00	0.10424901440 01	0.1465767928D 01	0.18904127260 01	0.22913723620 01	0.26079358910 01	0.27644157030 01
0	-3.0	-2.6	-2.2	8. T	4.1-	0.7	9.9	7.9	0.5	9.0	0.	<b>*</b> .	æ.	2.2	5.6	3.0
	-	7	m	4	<b>5</b>	۰	_	80	•	2 ∶	= :	7	<u> </u>	=	2	16

Table 4-3 (Continued) 80 Items.

			_	*	*	*	:	:	*	۰	÷	-	*	*	*	*
€ype	-	_	_	_	4	4	4	4	4	4	4	-	4	4	9	_
¥	0.41618495270 01 -0.74741696490 00	0.4363392343B 01 -0.7130504683B 00	01 -0.16563597330 01	0.10600756100 01	0.30200645910 00	0.1713794882D 00	0.10728720840 00	0.30946102430-01	0.17441611000-03	0.39197532720-01	0.11905857390 00	0.1946334012D 00	0.24951310100 00	0.3725874764D 00	0.11630223870 01	-0.79577272180 00
82	0.4161849527D 01	0.4363392343D 01	0.4880204265D 01	0.5676538231D 01	0.5268327031D 01	0.39595873130 01	0.3367655272D 01	0.3184204066D 01	0.3136613483D 01	0.3165327718D 01	0.3266956323D 01	0.3479357234D 01	0.38996306490 01	0.4445489065D 01	0.4428438076D 01	0.3714654670D 01
8 1	0.29704504560 01	0.2118502571D 01	0.1590318454D 01	0.13544140930 01	0.7549884295D 00	0.2498070160D 00	0.72592994530-01	0.13477792170-01	0.63463538320-04	0.14884069170-01	0.56833676910-01	0.13710411400 00	0.28846104740 00	0.54509296720 00	0.7581384074D 00	0.7630694956D 00
ų A	0.26272954670 01	0.1916118644D 01	0.1407817754D 01	0.80668034710 00	0.3105288636D 00	0.11170091580 00	0.5759775241D-01	0.4033752472D-01	0.3510334422D-01	0.36775965140-01	0.45673823780-01	0,66983054390-01	0.1172622204D 00	0.23446428500 00	0.43178731650 00	0.5999442991D 00
μ <sub>3</sub>	670 00 -0.12206132030 01	910 00 -0.7851874440D 00	-0.4963904043D 00	-0.2693637590D 00	-0.1039422429D 00	-0.3440387993D-01	3.1307792836D 00 -0.1274253358D-01	-0.4383698144D-02	0.27411181590-03	0.4317376154D-02	0.96927254150-02	0.19137036620-01	0.38783282780-01	0.81255572200-01	0.1519283174D 00	0.2225493908D 00
<sup>n</sup> 2	0.79453177670 00	0.66267267910 00	0.5370988455p 00 -0.4963904043p	0.37697187930 00	0.24278095980 00	0.16795904820 00	0.1307792836D 00	0.11255224860 00	0.10578978730 00	0.10778856720 00	0.1182393468D 00	0.13874999080 00	0.17340727720 00	0.22965641210 00	0.3122551806D 00	0.4018798601D 00
Į,	-3.0 -0.2544633344D 01	-0.2497159606D 01	-0.2261945440D 01	-0.15811691170 01	-0.1452359535p 01	-0.1028637569D 01	-0.6141049964D 00	-0.2042112360D 00	0.20375304620 00	0.61141657640 00	0.10200551850 01	0.14309887400 01	0.18459205230 01	0.22668835300 01	0.26915974850 01	0.3094765726D 01
Ф	-3.0	-2.6	-2.2	-1.8	-1.4	0.1-	9.0	9	0.2	9.0	1:0	1.4	e: -	2.2	5.6	3.0
į		7	m	•	~	9	~	œ	6	9	=	2	2	2	2	9

Table 4-3 (Continued) 120 Items.

1-3-0   1-280905511380   10.71457512880   10.0-1010276004D   10.2400706125D   10.2597282874D   10.4701572264D   10.1908106380D   10.1908106380D   10.2400706125D   10.2057761054D   10.4701572264D   10.1908106380D   10.2377252123D   10.23772522D-01   10.23772522D-01   10.2377252D-01   10.2377272D-01   10.237727D-01   10.
0.289955118B 01         0.7145/312880 00         0.0.1010276004b 01         0.2400706125b 01         0.2199282814b 01         0.47015/3264b 01         0.7185/31284b 01         0.7187/3284b 01
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$
u1         u2         u3         u3<
-0.2809055138D 01 0.7145731288D 00 -0.1010276004D 01 0.2666254296D 00 -0.6118452090D 00 0.2285895226D 01 0.5666254296D 00 -0.6118452090D 00 0.2285895226D 01 0.2377323123D 00 -0.3249653574D 00 0.21267958649D 00 0.2377323123D 00 -0.1267910526D-01 0.101839589BD 01 0.1504433032D 00 -0.1267910526D-01 0.101839599BD 00 0.7391583505D-01 0.18598939391D-02 0.1013138233D 01 0.739158350D-01 0.1791933534D-02 0.1013138233D 01 0.7731326070D-01 0.75838937770D-02 0.1829688238D 01 0.7731326070D-01 0.75838936D-01 0.1424389804D-01 0.2243050086D 01 0.143476612D 00 0.2348389804D-01 0.2662288395D 01 0.2740658317D 00 0.1289712729D 00
0.12809055138D 01 0.7145751 0.285895526D 01 0.5666254 0.0.285895226D 01 0.3924160 0.1859584493D 01 0.3924160 0.1859584493D 01 0.23777325 0.1018359698D 01 0.1504433 0.1018359698D 01 0.1050403 0.2027294066D 00 0.7391583 0.1013138233D 00 0.7081692 0.1013138233D 01 0.6990595 0.1829688238D 01 0.6990595 0.1829688238D 01 0.1433476 0.2243050086D 01 0.1433476
0.28599551360 01 0.7145751 -0.2858952260 01 0.5666254 -0.2858952260 01 0.5666255 -0.18595844930 01 0.2377325 -0.10183596980 01 0.1504433 -0.20272940860 01 0.1504433 -0.20272940860 00 0.7391583 0.20248903170 00 0.7391583 0.10131382330 01 0.6990385 0.18296882380 01 0.1433476 0.22430500860 01 0.1433476 0.26622983950 01 0.1433476
0.2809055138D 01 -0.2809055138D 01 -0.265695308D 01 -0.1839584493D 01 -0.1839584493D 01 -0.1018369698D 01 -0.0071449873D 00 -0.202724698D 01 0.00264639D 00 0.1013138233D 01 0.182968238D 01 0.182968238D 01 0.2243050086D 01 0.2243050086D 01
1 -3.0 2 -2.6 4 -1.8 5 -1.4 6 -1.0 7 -0.6 8 -0.2 9 0.2 10 0.6 11 1.9 11 1.9 12 1.4 13 1.3 16 3.0
12646

Table 4-3 (Continued) 200 Items.

1 -3.0
u, 1         u, 2         u, 3         u, 4         B         E           -0.3019827664b 01         0.5837650349b 00         -0.7191763817b 00         0.1949663689b 01         0.26600701537b 01         0.5722329012b 01           -0.2686835602b 01         0.2388337558b 00         -0.3572410967b 00         0.1024986348b 00         0.11750474b 01         0.6789645671b 01           -0.2686835602b 01         0.2189116777b 00         -0.313834500         0.320410284p 00         0.135004747b 01         0.6789645671b 01           -0.1834165215b 01         0.2189116777b 00         -0.3138384316b-01         0.74128487837b-01         0.4771883111b 01         0.67896697b 00         0.4771883111b 01           -0.18419223772b 01         0.6279865242b-01         -0.1023087834b-01         0.2567198076b-01         0.6174703200b 00         0.4471883111b 01           -0.184100177892b 01         0.653973896b 00         0.65397386b-02         0.1023087834b-01         0.2273481951b-01         0.3169587b-01           -0.2016627315b 00         0.4383977901b-01         0.6633889971302b-02         0.51659674b-02         0.1165747b-02         0.1165747b-02         0.306997173b-02           0.001644541545b 01         0.453866b-02         0.13867271b-02         0.16538966b-02         0.16538966b-02         0.1653866b-02         0.11657174b-02         0.11657174b-02 <t< th=""></t<>
-0.3019827604b 01 0.5837050349b 00 -0.7191763817b 00 0.1949663689b 01 0.2600701537b 01 -0.2666835602b 01 0.3885397558b 00 -0.372410967b 00 0.1024966343b 01 0.2175787308b 01 -0.261305892b 01 0.2885397558b 00 -0.1398248753b 00 0.3204102649b 00 0.135047647b 01 -0.1287521271b 00 0.0.1398248753b 00 0.3204102649b 00 0.135047647b 01 -0.128752372b 01 0.25879932056b 01 0.261305892b 01 0.2573986597b 01 0.257388856b 00 0.257388856b 00 0.25738859733b 00 0.257388597b 01 0.25738855b 01 0.257389575b 01 0.257
-0.3019827604b 01 0.5837050349b 00 -0.7191763817b 00 0.1949663689b 01 -0.2686835602b 01 0.388397558b 00 -0.372410967b 00 0.1949663689b 01 -0.2261305892b 01 0.388397558b 00 -0.1198248753b 00 0.3204102849b 00 -0.1834165215b 01 0.2187512171b 00 -0.1198248753b 00 0.3204102849b 00 -0.1834165215b 01 0.258991207b-01 -0.1033728b 00 0.3204102849b 00 -0.1198248753b 00 0.3204102849b 00 0.256198076b-01 -0.100717892b 01 0.6279845242b-01 -0.4048112768b-02 0.1275396788b-01 -0.4048112768b-02 0.1275396788b-01 0.6279845242b-01 0.6183186699b-03 0.5889973302b-02 0.2016026735b 00 0.4383977901b-01 -0.163186699b-03 0.5889973302b-02 0.2014809303b 00 0.4383977901b-01 0.618388693b-02 0.64544545b 01 0.4571034739b-01 0.466691608b-02 0.6454645b-01 0.4571034739b-01 0.4666691608b-02 0.1339771722b-01 0.2255026977b 01 0.4571034738b-01 0.89018528609-02 0.1339771722b-01 0.2255026977b 01 0.15093122b 00 0.3867165310b-01 0.4337861173b-01 0.3867165310b-01 0.4337861173b-01 0.3867165310b-01 0.433788b-01 0.3867165310b-01 0.433788b-01 0.3867165310b-01 0.433788b-01 0.3867165310b-01 0.433788b-01 0.3867165310b-01 0.433788b-01 0.3867165310b-01 0.433788b-01 0.3867165310b-01 0.39671633018b-01 0.3867165310b-01 0.39671653018b-01 0.
-0.3019827604 D 0.5837050349 D 00 -0.7191763817 D 00 -0.2686835602 D 0 0.3885397580 D 0 -0.3572410967 D 00 -0.2686835602 D 0 0.3885397580 D 0 -0.3572410967 D 0 -0.261305892 D 0 0.28851977 D 0 -0.119824875 D 0 -0.1394165215 D 0 0.28871217 D 0 -0.119824875 D 0 0.182717 D 0 -0.3138384316 D 0 -0.1193237 D 0 -0.119328 D 0 -0.3138384316 D 0 -0.100717892 D 0 0.627984524 2 D 0 0.527984524 2 D 0 0.547984524 2 D 0 0.547984534 2 D 0 0.54798454 2 D 0 0.5479845
-0.3019827604B 01 0.5837050 -0.266835602B 01 0.3837050 -0.261305892B 01 0.2895116 -0.18418223772B 01 0.6259935 -0.1010717892B 01 0.6259935 -0.6053738506B 00 0.5033755 -0.2016026735B 00 0.433779 0.201489494B 01 0.4527069 0.1817444827B 01 0.6432786 0.2625056977B 01 0.432786 0.2635848791B 01 0.1087017
-0.3019827604 D 0.5837050 -0.266835602 D 0 0.3863397 -0.2261305892 D 0 0.2189116 -0.1834165215 D 0 0.1287512 -0.1419223772 D 0 0.6259932 -0.1010717892 D 0 0.6559935 -0.2016609303 D 0 0.43375 0.6044541545 D 0 0.432769 0.1817414827 D 0 0.452769 0.1817414827 D 0 0.6432769 0.2225026977 D 0 0.632769 0.2635848791 D 0 0.1509503
1 1 3.0 9 9 1.3 6

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Conditional Mean  $\mu_1^{f b}$  , Second to Fourth Moments,  $\mu_2$  ,  $\mu_3$  and  $\mu_4$  , Indices  $eta_1$  and  $eta_2$  , Pearson's Criterion  $\kappa$  and Pearson's Type of Distribution Obtained at Sixteen Different Values of 0 , for Each of the Five Hypothetical Tests of Equivalent Items on the Three-Parameter Logistic Model with ag = 0.50 , bg \* 0.00 and cg = 0.25 . Moments Were Calculated by "Ignoring" Negative and Positive Infinities. The Mark \*\* Indicates That the Sum Total of the Probabilities for Finite Values of e Is Greater Than, or Equal to, 0.99 and Less Than 0.99999 , and \* Means It Is Greater Than, or Equal to, 0.99 and Less Than 0.99999 . 20 Items.

								*	*	*	*					
type		_	_	_	_		4	~	_	_	4	_	_	_	_	_
¥	0.3369776646b 01 -0.8046147200b 00	0.3278108206p 01 -0.6592196759p 00	-0.4794440684D 00	-0.3455532639D 00	01 -0.30551953380 00	01 -0.6550512194D 00	0.30923695650 00	0.50109550650-01	0.39 6087 554 50-04	0.47762721370-01	0.51018886490 00	-0.2158562139D 00	-0.1387674878D 00	01 -0.21722056670 00	0.2344773068D 01 -0.4461483886D 00	0.2329137598D 01 -0.7189529825D 00
β2	0.3369776646D 01	0.32781082060 01	0.3157516678D 01 -0.4794440684D	0.3041798358D 01 -0.3455532639D	0.3049408909D 01	0.32881931130 01	0.37064 26020D 01	0.3977489306D 91	0.3929977099D 01	0.3751953849D 01	0.3401796914D 01	0.2933658616D 01	0.2578349677D 01 -0.1387674878D	0.2396398858D 01	0.2344773068D 01	0.2329137598D 01
e <sub>1</sub>	0.2965285351D 01	0.2581468239D 01	0.1883627092D 01	0.1040622676D 01	0.5078747144D 00	0.3274886059D 00	0.2529790674D 00	0.10524259710 00	0.96441575120-04	0.78519242650-01	0.17716508550 00	0.2002773485b 00	0.28761282090 00	0.7601914692D 00	0.1709713365b 01	0.2194049619D 01
ц	0.22985877070 01	0.1891765071D 01	0.15994819610 01	0.1509876767D 01	0.16063170935 01	0.1721702109D 01	0.16540764210 01	0.1394697245D 01	0.1176740085D 01	0.1135685066D 01	0.11481929300 01	0.f051465197D 01	0.8483791224D 00	0.68292489360 00	0.75263030990 00	0.12520203820 01
µ3	MID 00 -0.1292493057D 01	200 00 -0.10638155420 01	OAD 00 -0.8240863755D 00	-0.6032605890D 00	00 -0.4406461780D 00	00 -0.3522480675D 00	mo -0.2746265175p 00	00 -0.1478253684D 00	0 -0.39751181670-02	0.11435057990 00	0.18638842270 00	0.20730267800 00	0.2329915862b 00	0.34007278320 00	0.55759942690 00	0.92989821080 00
μ <sub>2</sub>	0.82590478410 00	0.75966472200 00	0.711732580AD 00	0.704 539 814 6D 00 -0.6032605890D	0.7257846987D 00	210	0.65803638530 00	0.5921550824 D 00	0000	0.5501741911D 00	0.580969379ub 00	0.59867712440 00	0.57361972660 00	0.53383484720 00	0.56655286950 00	0.7331758079D 00
- <b>-</b>	-3.0 -0.1274142202B 01	-2.6  -0.135\$360171D 01	-0.1411431610D 01	-0.1400376380D 01	-0.1275352628D 01	-0.1014494476D 01	-0.64426505550 00	-0.2198328657D CO	0.2175303247D 00	0.6532510586D no	0.1077792142b of	0.14635064120 01	0.1759588524D 01	0.1913839057D 01	0.19054493780 01	0.17376636790 01
6	-3.0	-2.6	-2.2	. i.	4:1-	٠	4.0	7.7	0.2	9.0	0.1	1.4	1.8	2.2	2.6	3.0
		7	•	*	\$	Ś	~	•	0	01	11	12	<b>P</b>	*	15	9:

Table 4-4 (Continued) 40 Items.

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egya		•
<b>Y</b>	0.3587863797D 01 -0.8028923678D 00 0.3641536171D 01 -0.6533948898D 00 0.3622938921D 01 -0.5196673704D 00 0.3741257845D 01 -0.5872968190D 00 0.4372091374D 01 -0.587290988D 01 0.4372091374D 01 -0.151424531D 00 0.3369695725D 01 -0.151424531D 00 0.3981813215D 01 -0.130810464D 00 0.3886292827D 01 -0.3141707362D 00 0.3886292827D 01 -0.246434148D 00 0.277082246D 01 -0.246434783D 01	m 70/0/06/766-0-
8 2	0.3587663797D 01 0.3622938921D 01 0.3622938921D 01 0.4226919040D 01 0.4372091374D 01 0.4372091374D 01 0.4372091374D 01 0.368981472D 01 0.368981472D 01 0.3681813215D 01 0.3686292827D 01	10 764704906710
91	0.3061908364 D 01 0.2613149866 D 01 0.1764009785 D 01 0.1107727676 D 01 0.8919202457 D 00 0.769718250 D 00 0.3253718250 D 00 0.6164235435-01 0.4392563535-01 0.1834143582 D 00 0.501827301430 D 00 0.51827301430 D 00	10 760760710410
h h	0.3034006235D 01 0.2278788439D 01 0.1632256185D 01 0.1365140022D 01 0.4701595799D 00 0.4701595799D 00 0.2636467214D 00 0.2177173811D 00 0.2177173811D 00 0.2256843479D 00 0.4780547473D 00 0.4780547473D 00 0.4680547473D 00	
нз	71D 00 -0.1543056044D 01 72D 00 -0.113735670BD 01 72D 00 -0.8002360399D 00 03D 00 -0.864994837D 00 36D 00 -0.4046019422D 00 53D 00 -0.4046019422D 00 53D 00 -0.345412197D-01 53D 00 -0.345412197D-01 53D 00 -0.345412197D-01 66D 00 0.2566470752D-01 66D 00 0.2566470752D-01 66D 00 0.2566976D 00 52D 00 0.2566971282D 00 52D 00 0.2566971282D 00 6296070313D 00	0.44 007 040 11 W
n 2	0.9195818771D 00 0.7910604823D 00 0.7133649072D 00 0.6603190403D 00 0.5682986636D 00 0.329276448D 00 0.329276448D 00 0.2684038235D 00 0.268211875D 00 0.249116519D 00 0.2493116519D 00 0.2493154466D 00	M 41 1707(677610
	0.1838728208D 01 0.1918428445D 01 0.1918428445D 01 0.1770976093D 01 0.1467521253D 01 0.1064935139D 01 0.20753858D 00 0.20753858D 00 0.20753858D 00 0.206547008D 01 0.1471104392D 01 0.2283737293D 01 0.2283737293D 01 0.2283737293D 01	10 7 10 10 10 10 10 10
ø	13.0 -2.6 -2.6 -1.3 -1.6 -0.6 -0.2 -0.2 -0.6 -0.2 -1.6 -1.6 -1.6 -1.6 -1.6 -1.6 -1.6 -1.6	>
	125459786212512	٥

Table 4-4 (Continued) 80 Items.

<del></del>		_	_	*	<u>*</u>	*	ئے	÷	*	<u>:</u>	*	*	<u>*</u>	<u>*</u>	÷	_
€yp€	_	_	_	_	<u> </u>	_	_	_	_	_	_	_	_	_	_	
¥	0.4159382861D 01 -0.7891917016D 00	01 -0.69979243200 00	-0.1041811831D 01	0.26829124815 01	0.4123293391D 00	0.1837191303D 00	0.1132917442D 00	0.3693296510D-01	0.13595733080-05	0.3510211820D-01	9.1143359864D 00	0.1896899612D 00	0.2523687390D 00	0.4187427012D 00	0.2097763611D 01	-0.5806331570D 00
β2	0.4159382861D 01	0.43250695450 01	0.4658392385D 01	0.54421557720 01	0.5618593677D 01	0.43567913320 01	0.3489293211D 01	0.32237734050 01	0.31553718210 01	0.3181696827D 01	0.329302994D 01	0.3533575925p 01	0.39963156190 01	0.4482406066D 01	0.42914559550 01	0.3541950903D 01
l <sub>l</sub>	0.3156763002D 01	0.23783950990 01	0.16902652210 01	0.14446715190 01	0.98667997730 00	0.3614976952D 00	0.99815993310-01	0.1910622767D-01	0.13910487160-05	0.14856734230-01	0.60631589030-01	0.15006389180 00	0.3199904310p 00	0.5851689300b 00	0.7541058603p 00	0.74444167330 00
μų	0.30745356670 01	0.22369734730 01	0.1700661035p 01	0.1104847784D 01	0.49048920790 00	0.17116484460 00	0.78378108020-01	0.51631901510-01	0.43480593250-01	0.44677992020-01	0.54962876570-01	0.8068064130D-01	0.14237266160 00	0.2796250364D 00	0.4835979400D 00	0.6264412698D 00
μ3	0490 00 -0.14163936370 01	00 -0.94057364370 00	00 01669699019 00	00 -0.36352406470 00	00 -0.15952695860 00	00 -0.53056503260-01	00 -0.18331290900-01	00 -0.62230412941-02	-0.4743565027D-04	0.49720766565-02	0.11434174110-01	0.22753818450-01	0.46386714530-01	0.95485905700-01	0.16869857875 00	0.23531180030 00
η	0.8597562049D 00	0.71917382020 00	0.60421408790,00	0.45057359820 00	0.29546151140 00	0.1982092440D 00	0.14987481330 00	0.12655427080 00	0.11738766370 00	0.11849974778 00	C.1291923755D 00	0.15110452050 00	0.18874845730 00	0.24976548790 00	0.3356911496D 00	0.42055123450 00
ľπ	-3.0 -0.2398465923D 01	-0.23975791560 01	-0.2224171369D 01	-0.1883256201D 01	-0.1461503897n 01	-0.1033730718D 01	-0.6162447044D 00	-0.204789384910 00	0.20413556390 00	0.61253536340 00	0.10218940380 01	0.1433694292D 01	0.1649804622D 01	0.22720763310 01	0.26956665150 01	0.30880365930 01
6	-3.0	-2.6	-2.2	æ: -	7.1-	-1.0	9.9	-0.2	0.2	0.6	0.1	7:	1.8	2.2	2.6	3.0
	-	7	6	4	5	9	1	80	6	0	1	12		*	15	91
														_		

Table 4-4 (Continued) 120 Items.

Pd4-	T =	_	9	*	*	*	*	**	**	* *	÷	+	*	*	*	÷
DGA3	L.	9	7	0	0	0	2	_	5	_	-	-	-	9	8	=
¥	-0.8112523446D 0	01 -0.98216162120	0.4527505741D 0	0.5828004 105D 0	0.23718740650 0	0.1839095612D 0	0.11644103160 00	0.35766736340-01	0.35913946590-05	0.33842105660-01	0.11309825210 00	0.1963049656D 0	0.2550885205D 0	0.2886905209D 0	0.3985536618D 0	0.1187318279D 01
R 2	0.4655665222D 01 -0.8112523444D 00	0.4990939961D 01	0.57999376210 01	0.63182591990 01	0.48820533390 01	0.3642623264D 01	0.32641847360 01	0.31355763700 01	0.3097654159D 01	0.31125097850 01	0.31736388360 01	0.3293974204D 01	0.3517828740D 01	0.3952068568D 01	0.4538417882D 01	0.4547365924D 01
l'a	0.3079711053b 01	0.22495755910 01	0.1851667325D 01	0.13925746230 01	0.56420963720 00	0.1767371862D 00	0.5% 55 56 50 50 50	0.11281010600-01	0.93498548970-06	0.8923320072D-02	0.35826487550-01	0.85152610930-01	0.17060454160 00	0.3269677432b 00	0.5942793712p 00	0.8224387289b do
Ħ	0.2868823041D 01	0.2029676857p 01	0.12930901550 01	0.5560985450p 00	0.16189612100 00	0.37516121660-01	0.30902172450-01	0.21564149690-01	0.18427103690-01	0.19814766150-01	0.22569886220-01	0. MA16841470-01	0.50584940470-01	0.95510224330-01	0.2040633279p 00	0.39723815380 00
μ <sub>3</sub>	578D 00 -0.1220524491D C1	-0.7638071356p 00	-0.4415049665D 00	-0.1906887091D 00	-0.5837080631D-01	MOD 00 -0.1872501948D-01	115D-01 -0.7144189844D-02	132D-01   -0.2536502063D-02	-0.2071192900D-O4	0.2047879082D-02	0.46353338280-02	0.89059597790-02	0.17191622400-01	0.35048666620-01	0.75273253900-01	0.1457203029b 00
μ <sub>2</sub>	0.78498436780 00	0.6377086049D 00 -0.7638071356D	0.4721747306D 00	0.2966724104D 00	0.1821029418D 00	0.1256572840D 00	0.97298723150-01	0.8292920032D-01	0.771280009910-01	0.77748863550-01	0.043307443910-01	0.97660999200-01	0.11991493470 00	0.15545786430 00	0.2120460768D 00	0.2955599102D 00
- II	-0.2684525339D 01	-0.2579263044D 01	-0.22822356510 01	-0.1870300041B 01	-0.1440168297E 01	-0.1021467690D 01	-0.51046666230 00	-0.2030846812D 00	0.20273903625 00	0.6082324790D 00	0.10143230680 01	0.14219162670 01	0.1832126992D 01	0.22465248270 01	0.26671269860 01	0.30917788210 01
Ф	-3.0	-2.6	-2.2	-1.8	7:1-	_	9.	9.7	0.7	9.0	0:	<u> </u>	æ:	2.2	7.6	3.0
	-	~	^		~	ø	~	æ	•	9	Ξ	12	£	=	15	91
		_	_	_	_		_	_			_		_	_		

Table 4-4 (Continued) 200 Items.

J

-46	]=		*	+	*	*	**	+	*	*	*	*	*	*	*	*
∌dk:	+-	: 2	, 6	8	8	8	8	=	2		8	8	8	8	8	8
¥	-0-1082888479n	-0.1873294638n	0.6750613826D	0.2655606464D	0.2427905301D	0.20081469010	0.1162434197D 00	0.34849837190-01	0.39788885860-05	0.32877222520-01	0.1115186255D 00	0.19815650230	0.2688219870D	0.3137187221D 0	0.32744652410 00	0.35268087220 00
8 2	0.55171711396n ol -0.108288479n ol	0.64161129590 01 -0.18727946380	0.708984 204 50 01	0.52534 10032D OI	0.3721396798D 01	0.32945785530 01	0.3140194809D 01	0.3076210200D 01	0.30561157820 01	0.30640220570 01	0.30961910800 01	0.31565279660 01	0.32575555100 01	0.34285641930 01	0.3745766886D 01	0.4325447234D 01
fa <sub>1</sub>	0.2865468704D 01	0.2326518861D 01	0.17648896370 01	0.7049404795D 00	0.2298582819D 00	0.86410867990-01	0.29511074280-01	0.62068229160-02	0.59534850810-06	0.49548087720-02	0.1971273114 0-01	0.45841852700-01	0.8801572994 D-01	0.1562301145p 00	0.27351843390 00	0.4906363214D 00
2	0.2437106683D 01	0.1449886676D 01	0.56453163530 00	0.1339758650b 00	0.38588393300-01	0.17485312160-01	0.1029579482D-01	0.7418568817D-02	0.63990189310-02	0.65059662430-02	0.76783695430-02	0.10357614060-01	0.15756127380-01	0.26840493655-01	0.51642952380-01	0.11417112580 00
E A	00 -0.91720493630 00	00 -0.4999192177D 00	00 -0.19913498690 00	00 -0.53581538300-01	0 00 -0.15579126920-01	D-01 -0.5780152890D-02	D-01 (-0.2353802260D-02	D-01  -0.8573591139p-03	P-01 (-0.75525451170-05)	0.69627112920-03	0.1560286462p-02	0.29354091460-02	0.54412463790-02	0.10402579320-01	0.2104243711p-01	0.45869477870-01
, n	0.6646286102D 00	0.47536918810 00	0.28217976160 00	0.15969548410 00	0.1018299096D 00	0.7285120867D-01				0.4607973354 D-01	0.4979900063D-01	0.57282905960-01	0.69547068570-01	0.8847877618D-01	0.11741812970 00	0.16246605410 00
- u	-3.0 -0.2948729075D 01	-2.6  -0.2679829188D 01	-0.22733515600 01	-0.1841799699D 01	-0.1422847948D 01	-0.1012441478D 01	-0.6061242348D 00	-0.2018029370D 00	0.20163490130 00	0.60488288380 00	0.1008471524D 01	0.14129130380 01	0.1818810813D 01	0.22269779560 01	0.26386134640 01	0.30555498150 01
æ	-3.0	-2.6	-2.2	-1.8	-1.4	_	9.0	9.5	0.2	9.0	0.	4.	æ:	2.2	2.6	3.0
	-	7	<u></u>	4	S	9	_	<b>8</b> 0	•	01	=	12	5	<b>*</b>	2	9

(4.2) 
$$\mu_{k} = E(\{\hat{\theta}_{t} - \mu_{1}^{t}\}^{k} | \theta)$$
,

for k=2,3,4 . In the same table, also presented are the indices  $\beta_1$  and  $\beta_2$  and Pearson's criterion  $\kappa$  , which are defined by

$$\beta_1 = \mu_3^2 \ \mu_2^{-3} \ ,$$

$$(4.4) \beta_2 = \mu_4 \mu_2^{-2}$$

and

(4.5) 
$$\kappa = \beta_1(\beta_2+3)^2[4(2\beta_2-3\beta_1-6)(4\beta_2-3\beta_1)]^{-1}$$
.

This criterion  $\kappa$  is used to determine which type of Pearson's distributions should be chosen to fit our empirical distribution (cf. Elderton and Johnson, 1969; Johnson and Kotz, 1970), and those types are given in the last columns of Tables 4-2 through 4-4.

We realize that those moments and indices cannot seriously be taken into consideration unless the two probabilities assigned to the negative and positive infinities, which are presented in Table 4-1, are negligibly small. Those cases are indicated in Tables 4-2 through 4-4 by \*\* and \*, the former of which indicates that the sum total of the probabilities assigned to the finite values of  $\hat{\theta}_t$  is greater than, or equal to, 0.999999, and the latter means that it is greater than, or equal to, 0.999999 but less than 0.999999.

If a distribution is normal, then we will have  $\beta_1 = 0.00$ ,  $\beta_2 = 3.00$  and the criterion  $\kappa$  converges to zero. We anticipate that, since those five hypothetical tests consist of equivalent items, in the normal ogive model the convergence to the normality must be speediest at  $\theta = b_g$ , and in the three-parameter logistic model it must be fastest at

(4.6) 
$$\theta = b_g + (Da_g)^{-1} \log[\{1-4c_g+(1+8c_g)^{1/2}\}\{3-(1+8c_g)^{1/2}\}^{-1}]$$
,

at which the common item information function  $I_g(\theta)$  assumes the highest value. With our hypothetical tests of equivalent items, those values are 0.00 for the normal ogive model, 0.31428 for the three-parameter logistic model with  $c_g = 0.20$ , and 0.36695 for the three-parameter logistic model with  $c_g = 0.25$ .

Comparison of those three tables indicates that there exist substantial differences in the convergence to the normality of the conditional distribution of  $\hat{\theta}_t$ , given  $\theta$ , between the results on the normal ogive model and those on the three-parameter logistic model. For example, for n = 200, the result on the normal ogive model provides us with the regression which differs from  $\theta$  by less than 0.01 in absolute value,  $\theta_1$  which is less than 0.01,  $\theta_2$  which differs from 3.00 by less than 0.10 in absolute value, and  $\kappa$  which is less than 0.10 in absolute value, for as many as six points of  $\theta$ , i.e., -1.0, -0.6, -0.2, 0.2, 0.6 and 1.0, whereas the same is true for the results on the three-parameter logistic model only for three points of  $\theta$ , i.e., -0.2, 0.2 and 0.6 in each of the two cases where  $c_g$  = 0.20 and

 $c_g$  = 0.25 , respectively. As another example, for n = 80 , the above is true for as many as four points of  $\theta$  , i.e., -0.6 , -0.2 , 0.2 and 0.6 , on the normal ogive model, while at no point of  $\theta$  is it satisfied on the three-parameter logistic model in either of the two cases where  $c_g$  = 0.20 and  $c_g$  = 0.25 . If we relax this rule to  $|\mu_1' - \theta| < 0.03$  ,  $\beta_1 < 0.05$  ,  $|\beta_2 - 3| < 0.50$  , and  $|\kappa| < 0.25$  , then the resultant number of points at which this condition is satisfied is as shown in Table 4-5 for each test and each model. From this table, too, we can see an obvious effect of noise caused by random guessing in the three-parameter logistic model on the speed of convergence of the conditional distribution of  $\hat{\theta}_t$  , given  $\theta$ , to the normality.

Figures 4-1 through 4-3 present  $\mu_1$ , that is the regression of  $\hat{\theta}_t$  on  $\theta$ , and the confidence interval  $(\mu_1 - \mu_2^{1/2}, \mu_1 + \mu_2^{1/2})$  plotted against the sixteen points of  $\theta$ , together with the asymptotic, unbiased regression with the confidence interval  $(\theta - \{I(\theta)\}^{-1/2}, \theta + \{I(\theta)\}^{-1/2})$ , which were first presented in Figure 3-2 of the preceding section. Since those moments were computed by "ignoring" negative and positive infinities, we cannot take some sets of three points seriously if the probabilities assigned to either negative or positive infinities, or both, are substantially large. For this reason, in Figures 4-1 through 4-3, five different symbols are used to indicate the magnitude of the sum total of the probabilities assigned to the finite values of  $\hat{\theta}_t$ , which are shown in Table 4-6. The S shape observed in some of the graphs in those three figures is caused by smaller values of the sum total of those probabilities. In those graphs, when this sum is greater than, or equal

TABLE 4-5

Number of Points of  $\theta$  at which  $\left|\mu_1'-\theta\right|<0.03$ ,  $\beta_1<0.05$ ,  $\left|\beta_2-3\right|<0.50$  and  $\kappa<0.25$ , for Each of the Five Tests of Equivalent Items Following the Normal Ogive Model and the Three-Parameter Logistic Model with  $c_g=0.20$  and  $c_g=0.25$ .

n	Normal Ogive	3-P.L. c <sub>g</sub> =0.20	3-P.L. c <sub>g</sub> =0.25
20	4	0	0
40	6	2	2
80	8	3	3
120	8	5	4
200	10	6	6

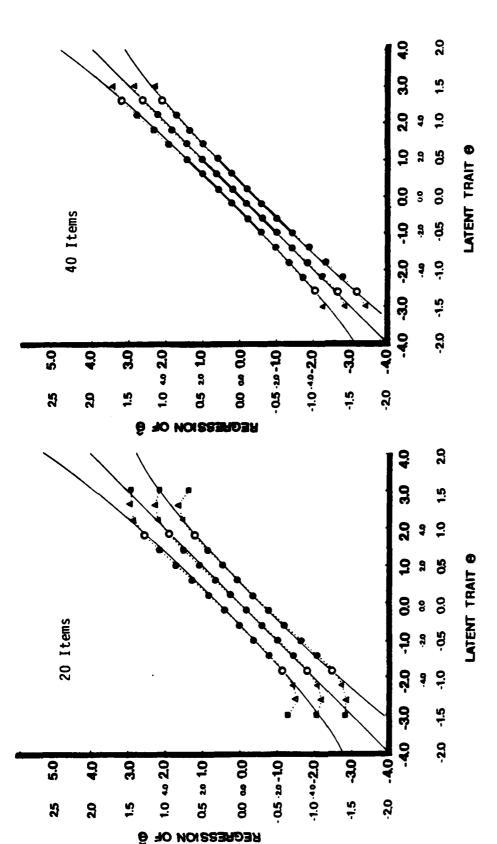


FIGURE 4-1

 $\theta$  ,  $\mu_1^1$  , and the Confidence Interval  $(\mu_1^1-\mu_2^{1/2},\ \mu_1^1+\mu_2^{1/2})$  Plotted against the Sixteen Points of  $\theta$ , Together with the Asymptotic, Unbiased Regression and the Confidence Interval  $(\theta-\{I(\theta)\}^{-1/2}, \theta+\{I(\theta)\}^{-1/2})$ , for Each of the Five Tests of Equivalent Items on the Normal Ogive , for Each of the Five Tests of Equivalent Items on the Normal Ogive Model with a = 0.50 and b = 0.00 . 5  $(\theta-\{I(\theta)\}^{-1/2})$ Regression of

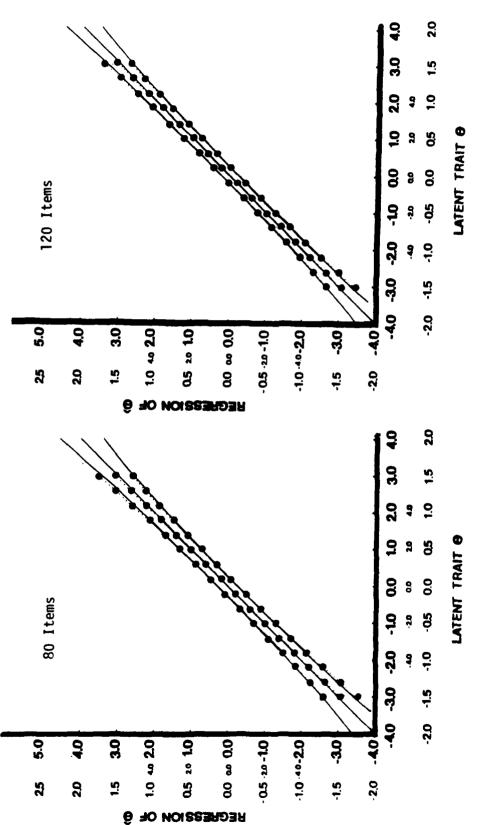


FIGURE 4-1 (Continued)

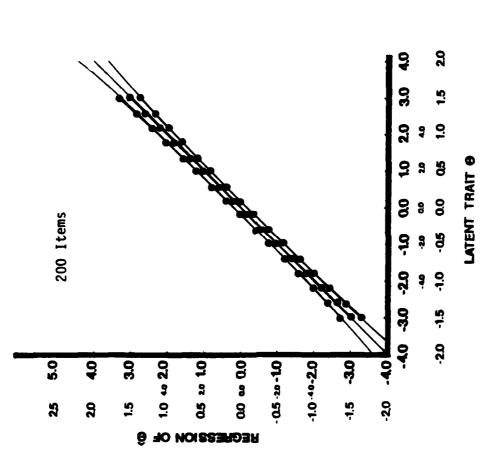
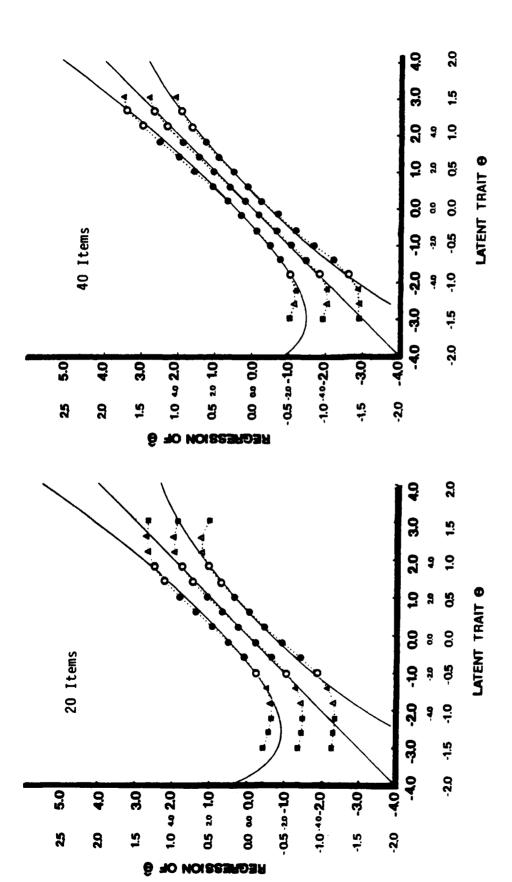


FIGURE 4-1 (Continued)



1

FIGURE 4-2

 $^{\theta}$  ,  $^{\mu_1'}$  , and the Confidence Interval  $(\mu_1'^{-\mu_2})^{1/2}$ ,  $\mu_1'^{+\mu_2})^{1/2}$ ) Plotted against the Points of  $\theta$  , Together with the Asymptotic, Unbiased Regression and the Confidence Interval  $(\theta-\{I(\theta)\}^{-1/2},\ \theta+\{I(\theta)\}^{-1/2})$  for Each of the confidence interval  $\{I(\theta)\}^{-1/2}$ ,  $\theta+\{I(\theta)\}^{-1/2}$ ), for Each of the Five Tests of Equivalent Items on the Three-Parameter Logistic Model with a = 0.50, b = 0.00 and c = 0.20. <u>ہ</u> Sixteen Points of Regression of

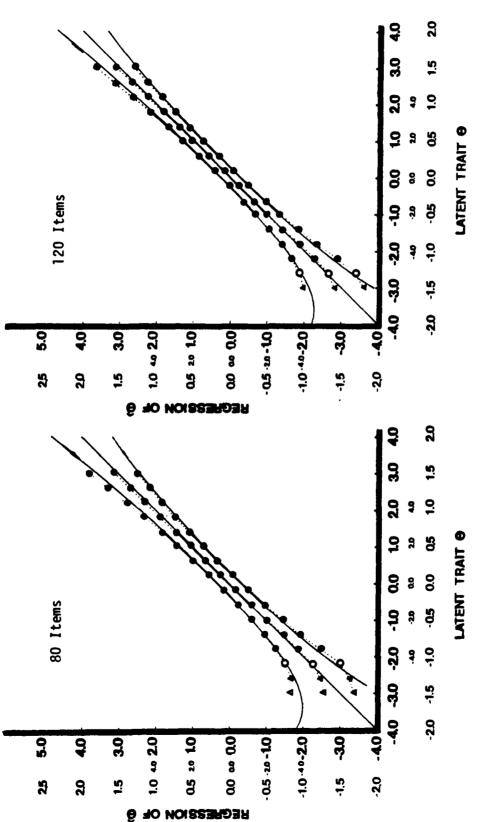


FIGURE 4-2 (Continued)

il

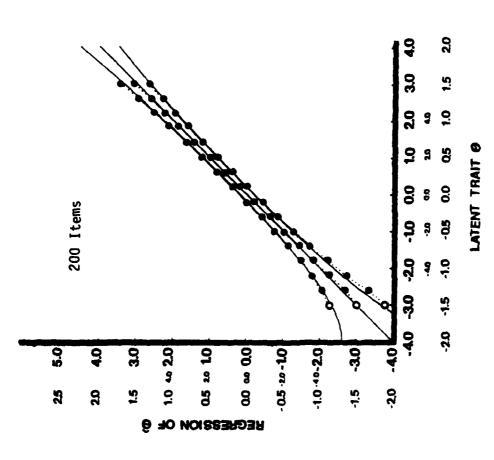


FIGURE 4-2 (Continued)

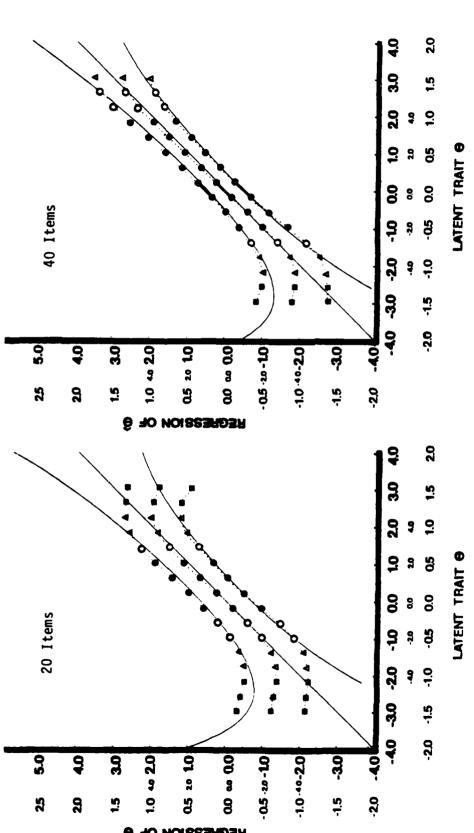


FIGURE 4-3

 $^{\theta}$  ,  $^{\mu_1}$  , and the Confidence Interval  $(^{\mu_1^{1}-\mu_2^{1/2}}, ^{\mu_1^{1}+\mu_2^{1/2}})$  Plotted against the Points of  $\theta$ , Together with the Asymptotic, Unbiased Regression and the Confidence Interval  $(\theta-\{I(\theta)\}^{-1/2},\ \theta+\{I(\theta)\}^{-1/2})$ , for Each of the Five Tests of Equivalent Items on the  $\{I(\theta)\}^{-1/2}$ ,  $\theta+\{I(\theta)\}^{-1/2}$ ), for Each of the Five Tests of Equivalent Items on the Three-Parameter Logistic Model with a = 0.50 , b = 0.00 and c = 0.25 . Sixteen Points of Regression of

V

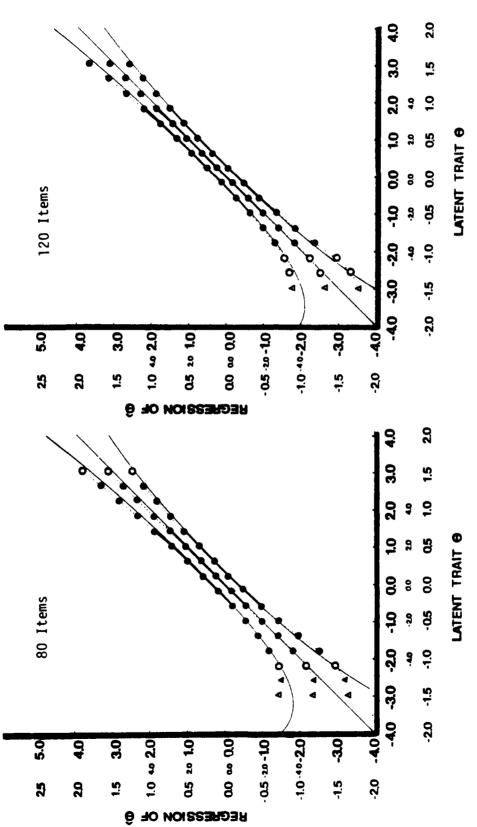


FIGURE 4-3 (Continued)

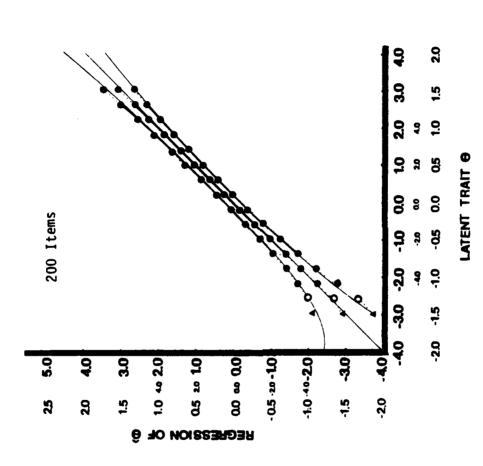


FIGURE 4-3 (Continued)

TABLE 4-6

Symbols for the Five Different Categories of the Sum of the Probabilities Assigned to Finite Values of the Maximum Likelihood Estimates.

Lower Endpoint (inclusive)	Upper Endpoint (exclusive)	Mark
	0.80	
0.80	0.90	Δ
0.90	0.95	<b>A</b>
0.95	0.99	0
0.99		•
1		

to, 0.999999 for two or more adjacent points of  $\,\theta$  , the solid circles are connected by a thicker line.

We can see from those three figures that those regressions and confidence intervals are very close to the asymptotic ones, for the points of  $\theta$  at which the sum total of the probabilities for finite values of  $\theta$  is no less than 0.99 and, especially, when the sum is greater than, or equal to, 0.999999, they practically lie on those lines. Again, we can see substantial differences with respect to the agreement between the results on the normal ogive model and those on the three-parameter logistic model.

## V Comparison of Tests of Non-Equivalent Items

We have seen in the preceding section that the speed of convergence to the normality of the conditional distribution of the maximum likelihood estimate, given  $\theta$ , is fairly high, even for a small number of equivalent items, if the values of  $\theta$  are close to the point at which the amount of test information is maximal, in each of the three cases in which the normal ogive model and the three-parameter logistic model with  $c_g = 0.20$  and  $c_g = 0.25$  are followed. The range of  $\theta$  for which this is the case is fairly small, however, for a smaller number of equivalent items, especially on the three-parameter logistic model. We notice that this interval of  $\theta$  may be enhanced, if we use non-equivalent test items. For this reason, in the present section, we shall observe the regressions and confidence intervals of three hypothetical tests of ten non-equivalent items, which follow the normal ogive model with the common discrimination parameter

 $a_g$  = 0.50 and with the difficulty parameters  $b_g$  shown in Table 5-1 for the ten items of each of the three tests, in comparison with those of a hypothetical test of ten equivalent items which follow the same model with  $a_g$  = 0.50 and  $b_g$  = 0.00. For convenience, hereafter, we shall call any tests having the sets of difficulty parameters shown in Table 5-1, Cases 1, 2 and 3, respectively.

As we did for the five hypothetical tests of 20, 40, 80, 120 and 200 equivalent items, the results of which were shown in the preceding section, the four conditional moments,  $\mu_1'$ ,  $\mu_2$ ,  $\mu_3$  and  $\mu_4$ , were computed by "ignoring" the probabilities assigned to the negative and positive infinities, for the hypothetical test of ten equivalent items and for the three hypothetical tests of ten non-equivalent items. Table 5-2 presents those probabilities assigned to the negative and positive infinities and their sum totals, for the four hypothetical tests of ten items. Unlike for the tests of equivalent items, for the three hypothetical tests of non-equivalent items the test score t is not a simple sufficient statistic for the response pattern V, so the maximum likelihood estimate  $\hat{\theta}_V$  must be obtained as the solution of

(5.1) 
$$\sum_{u_{g} \in V} A_{u_{g}}(\theta) = 0 ,$$

where  $\Lambda_{\mathrm{H}_{9}}(\gamma)$  is the basic function (Samejima, 1969, 1972) defined by

(5.2) 
$$A_{ug}(\cdot) = \begin{cases} = \frac{1}{2} \log Q_g(\cdot) & u_g = 0 \\ = \frac{1}{2} \log P_g(\cdot) & u_g = 1 \end{cases},$$

Item	Case 1	Case 2	Case 3
1 2 3 4 5 6 7 8 9	-2.7 -2.1 -1.5 -0.9 -0.3 0.3 0.9 1.5 2.1	-3.6 -2.8 -2.0 -1.2 -0.4 0.4 1.2 2.0 2.8 3.6	-4.5 -3.5 -2.5 -1.5 -0.5 0.5 1.5 2.5 3.5 4.5

TABLE 5-2

Sum Totals of Probabilities Assigned to Negative and Positive Infinities and Their Sum of the Four Hypothetical Tests of 10 Items Following the Normal Ogive Model. In all  $a_g \approx 0.50$  . Equivalent Case  $|b_g| \approx 0.00$  . Difficulty Parameters of the Three Non-Equivalent Cases Are Shown in Table 5-1. in the Conditional Distribution of  $\theta_{\mathbf{v}}$ , given  $\theta$  , at Twenty Different Values of Four Cases,

i	Negative	Negative Infinity			Positive Infinity	Inflatty			Total	a1	
and see and see	٤	-1.6 to 3.6	-4.5 to 4.5	Equivalent	-2.7 to 2.7	-3.6 to 3.6	-4.5 tc 4.5	Equivalent	-2.7 to 2.7	-3.6 to 3.6	-4.5 to 4.5
6. 47.346	0.425885	0.255897	0.122844	0.000000	0.00000.0	0.000000	0.000000	0.747240	0.426885	0.255897	0.122844
0.57 (P.H.3	2.310612	C.166274	0.069826	0.000000	0.00000	0.00000	0.00000.0	0.633883	0.310032	0.166274	0.069826
754005-11	0.205852	98//60.0	0.035580	0.000000	0.000000	0.000000	0.00000.0	0.500857	0.205352	9.097786	9.035580
1 0.361274	J. (22960	0.051314	0.016048	0.00000.0	0.00000.0	0.00000.0	000000::0	0.361274	0.122960	0.051314	0.015048
0.242719	0.044055	0.023572	0.006325	0.00000.5	0.000000	0.000000.0	0.000000	9.232710	0.064955	0.023472	0.005325
76262177	0.025811	\$5°000	0 002149	000000 ນ	0.00000.0	0.00000	0.00000.0	0.130792	0.029811	0.009454	0.002149
143241	0.011670	6,04.3218	C.C00621	0.000001	0.00000	0.00000	0.00000.0	0.062648	0.011679	0.003218	0.000621
7.11.69.85	0.001975	= 099918	0.000151	0.000008	0.00000.0	0.00000	0.00000	0.024993	0.003526	816000 0	0.000151
4,0381115	10001031	91.0000	0.000030	0.000066	0.000005	0.000001	0000000.0	0.008181	9:0100.0	0.000217	0.000030
3012 102	0.000224	0.030043	0.000005	9.000426	0.000039	0.00000	0.000001	0.002527	0 (00263	0.000048	9.00000.0
0.000426	0.000039	0.000006	0.000001	0.092102	0.000224	0.000041	0.000005	0.002527	0.000263	0.000048	90000000
94000015	0.000005	0.00000	0.000000.0	0.008115	0.001031	0.000216	0.000030	0.008181	0.001036	0.000217	0.000030
800000 c	0.000001	C.CUMMO	0.000000	0.024985	0.003826	0.000918	0.000151	0.024993	0.033826	0.000918	0.000151
1000000 T	0.00000.0	0.000000	0.000000	0.062647	0.011670	0.003218	0.000621	0.062648	0.011670	9.003218	0.000621
00000000	0.000000	0.000000	0.00000	0.130792	0.029811	0.009454	0.002149	0.130792	0.029811	0.009454	0.002149
00000071	0.000000	0.000000	0.000000	0.232710	0.064955	0.023672	0.006325	0.232710	0.064955	0.023672	0.006325
0.000000	0.0000000	0.000000	0.000000	0.361274	0.122960	0.051314	0.016048	0.361274	0.122960	0.051314	0.016048
0.000000	0.000000	0.000000	0.300000	0.500857	0.205852	0.097786	0.035580	0.500857	0.205852	0.097786	0.035580
0.00000	0.000000	0.000000	0.000000	0.633883	0.310032	0.166274	0.069826	0.633883	0.310032	0.166274	0.069826
0.00000	0.000000	0.000000	0.000000	0.747240	0.426885	0.255897	0.122844	0.747240	0.426885	0.255897	0.122844
	, L	7			,	1		ן [	4.		

with the item characteristic function  $P_g(\theta)$  replaced by the formula for that of the normal ogive model, which is given on the right hand side of (2.3), and  $Q_g(\theta) = 1 - P_g(\theta)$ . The conditional distribution of the maximum likelihood estimate  $\hat{\theta}_V$ , given  $\theta$ , cannot be simplified to any form as we did for equivalent items using the probability function of the binomial distribution of the test score, for the response pattern V is not unidimensionally ordered, and for other reasons. Thus in obtaining moments we must use the operating characteristic  $P_V(\theta)$  itself as the probability assigned to the maximum likelihood estimate  $\hat{\theta}_V$ , which is obtained from the operating characteristics of the item score through the formula

(5.3) 
$$P_{V}(\theta) = \sum_{u_{g} \in V} P_{g}(\theta)^{u_{g}} Q_{g}(\theta)^{1-u_{g}},$$

provided that the distributions of the item score  $u_g$  are conditionally independent, given  $\theta$ , for all the items of the test. Thus the computation of the moments is more complicated and time consuming, and we must deal with as many as  $2^n$  different values of  $\hat{\theta}_V$  instead of (n+1) different values of  $\hat{\theta}_t$ . For this reason, we are forced to restrict our observations to tests of only ten items, in which the number of different values of  $\hat{\theta}_V$  is 1,024.

Table 5-3 presents the four moments and indices  $\epsilon_1$  and  $\epsilon_2$ , and Pearson's criterion  $\kappa$  and distribution type, for twenty equally spaced values of  $\epsilon_1$ , -3.0 through 3.0, for each of the four tests of ten items. Just as in Tables 4-2 through 4-4, the symbol \*\* indicates that

k and Pearson's for Each of the Four Hypothetical Tests of 10 Items on the Calculated by "Ignoring" Negative and Positive Infinities. Is Greater Than, or Equal and  $\, \, \boldsymbol{\beta}_{2} \,$  , Pearson's Criterion y That the Sum Total of the Probabilities for Finite Values of  $\, heta_{f y}\,$ g. , Indices Type of Distribution Obtained at Sixteen Different Values of  $\theta$  , Normal Ogive Model with |a|=0.50 and |b|=0.00 . Homents Here \* Means It is Greater Than, or Equal to, 7 and r<sub>3</sub> , Second to Fourth Moments,  $\ \ \mu_{2}$ The Mark \*\* Indicates and . ۔ <u>۔</u> 0.999999 Conditional Mean

		0.999999 , and	• Mea	ins It is Greater Than, or Equal to,	0.99	and Less Than 0.999999	3999 . Equivalent Items	Items.	
		- <sub>a</sub>	2,1	<sup>17</sup>	H.	f 1	R 2	¥	EYPe
-3	-3.8		0.86943765220 00	76522D 00 -0.1660960145D 01	0.3198851306D 01	0.4197619715D 01	0.42317223480 01	-0.12501159840 01	_
~	47	-	0.88818657690 00	-0.1466490917D 01	0.24526551910 01	0.30693480530 01		-0.9867819727D	_
-3	-3.0	_	90501D 00		0.14901451400 01	0.2495894937D 01	0.25516843490 01	-0.8435883806D (0)	
-7	-2.6	-	\$0299D		0.80466733720 00	0.21146837260 01	0.23308051620 01	-0.6564121587D 00	_
-2	-2.2	_	49136D no	-0.3779668683D	0.54608045070 00	0.1215137067D 01	0.22754562980 01	-0.3041421246D 00	_
7	æ	_	63556D 00		0.6466038677D 00	0.26805015920 00	0.2409077403D 01	[-0.1117782452D 00	-
7	4. 1-		569430		0.96960555510 00	0.13121917060-01	0.25932889060 01	-0.2762418074D-01	_
;	0.1.		19168D		0.13538211510 01	0.11501369075-01	0.28265641190 01	-0.2270753323D-01	_
9	د	-	0.7305546994D 00	-0.6103036805p-01	0.16696717870 01	0.95528676680-02	0.3128424161D 01	0.31483577850-01	4
9	0.5	٠.	0.73989065060 00	-0.2800191476p-01	0.18380490220 01	0.19358550680-02	0.33575463070 01	0.2054361874D-02	4
0	~	0.2140103891D 00	0.73989065050 00	0.28001914760-01	0.1838049022D 01	0.19358550580-02	0.3357546307D 01	0.20543618740-02	4
0	، بع	0.6318842598D CO	-	0.6103036805p-01	0.1669671787D 01	0.95528676680-02	0.3128424161D 01	0.31483677850-01	4
	ο.	0.10118445720 01	0.69207191680 00	0.61744973690-01	0.13538211510 01	0.11501369070-01	0.28265641190 01	-0.22707533230-01	
	•	C.1311362462D 01		0.87019358480-01	0.96960555510 00	0.33121917065-01	0.2593288906D 01	-0.2762418074D-01	-
	œ	0.1482952102p 01	0.51807635560 00	0.1930628411D 00	0.64 660386770 00	0.26805015970 00	0.2409077403D 01	-0.11177824520 00	_
7	2.2	0.1498309158D 01	0.4898849136D 00	0.37796686830 00	0.54608045070 00	0.1215137067D 01	0.22754562980 01	-0.30414212460 00	_
~	5.6	0.1367732347D 01	0.58756402990 00	0.6549460283D 00	0.80466733720 00	0.2114683726D 01	0.2330805162D 01	-0.6564121587D 00	_
m	3.0	0.1137990812D 01	0.7641890501D 00	0.1055393380D 01	0.1490145140D OI	0.2495894937D 01	0.25516843490 01	-0.8435883806D 00	_
•	*	0.87070987260 00	0.88818657690 00	0.1466490917D 01	0.24526551910 01	0.30693480530 01	0.3109052716D 01	-0.9867819727D 00	_
_	œ	0.61822227290 00	0.86943765220 00	0.16609601450 01	0.31988513060 01	0.41976197150 01	3	-0.12501159840	_

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	-	_	_		_	_	_	*	•	<u>.</u>	<u>.</u>	*	٠	_	_	_	_	_		_
eype	8	8	90	-	_	-	0	0	_	7	7		<u>,</u>	<del>,</del>	_	_	0	0	8	8
¥	-0.78206087260	-0.6281343454D			-0.5979615574D-01	-0.4129024484D-01	-0.1006506596D OR	0.16715408070 00	0.30341677870-01	0.31070558330-02	0.310/0558330-02	0.30341677870-01	0.16715408070 00	-0.1c06506596D 00	-0.4129024484D-01	-0.5979615574D-01	-0.1464091996D 00	-0.3289658962D 00	-0.62813434540 Q	
R 2	0.2318393508D 01	0.2230471325D 01	0.22200400830 01	0.2314930069D 01	0.2469338490D 01	0.2656258974D 01	0.2902938729D 01	0.31586960510 01	0.3337078 SID 01	0.3411434267D 01	0.3411434267D 01	0.33370781510 01	0.3158690051D 01	0.2902938729D 01	0.26562589740 01	0.2469338590D 01	0.2314930069D 01	0.2220040083D 01	0.2230471325D 01	n :: a393508D 01
1 2	0.2255027308D 01	0.20101166510 01	0.13121742570 01	0.44416119650 00	0.1052889862D 00	0.44459233830-01	0.42787971629-01	0.4211957989D-01	9.2414257295p-01	0.33509478941-02	0.3350947894D-02	0.24142672950-01	0.42119579890-01	0.4278797162D-01	0.44459233830-01	0.1052889862D 00	0.44416119650 00	0.13121742570 01	0.20101166510 01	0.22550273780 01
٩n	0.34492048880 01	0.18764436120 01	0.12545157630 01	0.1292517898D 01	0.17055336720 01	0.2228812646p 01	0.26616799220 01	0.2890883027D 01	0.29266556610 01	0.2888294980D 01	0.2888294980D 01	0. 2926655661D 01	0.2890883027D 01	0.26616799220 01	0.22288126460 01	0.1705533672D 01	0.1292517898D 01	0.12545157630 01	0.1876443612D 01	0.344920* 8880 01
f n	-0.2022901719D 01	-0.1245416990D 01	-0.7465901173D 00	-0.4304714213D 00	-0.2458392521D 00	-0.18485591370 00	-0.1938203256D m	-0.1920368818D 00	-0.14081425230 00	-0.51093098490-01	0.51093098490-01	0.14081425230 00	0.19203688180 00	0.19382032560 00	0.18485591370 00	0.24583925210 00	0.43047142130 00	0.74659011730 00	0.1245416990D 01	0.20229017190 01
2 ا	0.12197362200 01	0.9172113852D 00 -0.1245416990D	00 000	8	0.83107426860 00	0.9160128673D 00	0.95754452970 00	0.95666911480 00		0.9201365218D 00	0.92013652180 00		0.95666911480 00	0.95754452970 00	0.91601286730 00	0.83107426860 00	0.74722147460 00	0.75172268000 00	0.91721138520 00	0.1219736220D 01
Į n	-0.1777506180D 01	-0.2033018862D 01	-0.2181635768D 01	-0.2190709487D 01	-0.2054376716D 01	-0.1794038253D 01	-0.1447233337D 01	-0.1051925295D 01	-0.6354503078p 00	-0.2122325534 D 00	0.2122325534D 00	0.63545030780 00	0.1051925295D 01	0.14472333370 01	0.17940382530 01	0.20543767160 01	0.2190709487D 01	0.21816357680 01	0.20330188620 01	0.1777506180D 01
درب	-3.8	-3.4	-3.0	-2.6	-2.7		<b>4.</b> I -	0.1-	9.0	-0.2	0.7	9.0	0.	4.	æ:	2.2	5.6	3.0	3.4	3.8
		~	<u>~</u>	<u>~</u>	5	40	_	•	0	<u> </u>					<u>~</u>	<u>-</u>		<u> </u>	<u> </u>	<del></del>

Table 5-3 (Continued) Case 2.

					<u>*</u>	*	<u>.</u>	*	_	<u>.</u>	*	<u>*</u>	*	*	_	_	_	_	
eype				_	_	_	_	_	<u> </u>	_	⁴	_	<u> </u>	_	_	_	_	_	<u>-</u>
¥	-0.5252571089D 00	-0.4532/3/610B ON	-0.4812502145D-01	-0.3853561806D-01	-0.8843341928D-01	0.5389765076D 00	0.67585735990-01	0.21055679650-01	0.2332755980D-02	0.23327559800-02	0.21055679650-01	0.67585735990-01	0.5389765076D 00	0.88433419280-01	-0.36535618060-01	-0.48125021450-01	-0.1137372387D 00	-0.2552737610D 00	-0.525257108910 00
8 2	0	0.21//0149330 01	5 8	0.26561938190 01	0.28817177720 01	0.30989093250 01	0.3240248821D 01	0.32900715110 01	0.3291860254p 01	0.3291860254p 01	0.32900715110 01	0.3240248821D 01	0.30989093250 01	0.28817177720 01	0.2656193819D 01	0.24705647300 01	0.2308685705p 01	0.21770149330 01	0.214 56070150 01
8.1	0.17975164870 01	0.1011/2/4090 01	T	0.4101821017b-01	0.4240218021D-01	0.4488554998D-01	0.33834974180-01	0.14945289730-01	0.17942236805-02	0.1794223680D-02	G. 1494528973D-01	0.33834974180-01	0.44885549980-01	0.42402180215-01	0.41016210170-01	0.80662758610-01	0.3100593634B 00	0.10117274090 01	0.17975164870 01
T. A.	0.2332965802D OI	0.17.381/9/820 01 0.19.9056700n 01	0.25088345300 01	0.31543495430 01	0.36439131560 01	0.3864303724D 01	0.3836452756b 01	0.3692626247D 01	0.35791551920 01	0.3579155192D 01	0.3692626247D 01	0.3836452756D 01	0.3864303724D 01	0.36439131560 01	0.315436330 01	0.2508834530D 01	0.1929056700D 01	0.1736179762D UI	0.2332965802b 01
r <sub>M</sub> 3	-0.1427595221D 01	-0.8493847701D 00		-0.2303965091D 00	-0.2455452423D 00	-0.2500057884D 00	-0.2087836783D 00	-0.13330599490 00	-0.45101672460-01	0.45101672460-01	0.1333059949D 00	0.20878367830 00	0.25000578848 00	0.24554524230 00	0.23039650910 00	0.2873033795b 00	0.48663972690 00	0.8495847701b 00	0.14275952210 01
μ 2	3530	0.8933433400	3100	0.1089745358D 01	0.1124496962D 01	0.11166863110 01	0.1086117379D of	0.10594122910 01	0.1042724480D 01	0.1042724480D 01	0.1059412291D 01	0.10881173790 01	0.1116686311D 01	0.1124496962D 01	0.1089745356D 01	0.10077113100 01	0.9140923819D 00	0.89354543520 00	0.10427473530 01
n H	-0.2533940348D 01	-0.26366996300 01 -0.363432430 01	-0.2471964635D 01	-0.2196809920D 01	-0.1845698126D 01	-0.1452769997D 01	-0.1041814025D 01	-0.6254491296D 00	-0.2084322761D 00	0.2084322761D 00	0.62544912960 00	0.10418140250 01	0.1452769997D 01	0.1645696126D 01	0.21968099200 01	0.24719646350 01	0.2634252412D 01	0.26566996500 01	0.2533940348B 01
8	-3.8	֓֞֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓֓	-2.6	-2.2	- 1.8	4.1-	-1.0	9.0	9.5	0.7	9.0	0:1	1:	8:	2.2	7.6	3.0	3.4	3.8
	- (	٦ ٣	٠.	S	٠	~	<b>6</b>	6	0	=	~	2	<b>≠</b>	2	9	_	00	2	ຂ

Table 5-3 (Continued) Case 3.

€àb€	_	_	_		_	÷	÷	<del>-</del>	÷	+	÷	+	+	<del>-</del>	÷	<del>:</del>		=	=	
	0	_	_	_	_	0	_	_	_	2	2	_:		_	0	_	_	_	_	0
¥	-0.1734113320D 00	-0.7318958947D-01	-0.3319063440D-01	-0.34582709930-01	-0.90458956050-01	0.5396334812D 00	0.8036739266D-01	0.3489776266D-0	0.12842799770-0	0.1500931952B 02	0.15009319520-02	0.1284279977D-0	0.3489776266D-01	0.80367392660-0	0.5396334812D 00	-0.9045895605D-01	-0.3458270993D-01	-0.3319063440b-01	-0.7318958947D-01	-0.1734113320D 00
82	0.2181598200D 01	0.2348055490D 01	0.251 624445D 01	0.27036018190 01	0.2907225439D 01	0.3078906746D 01	0.31739027820 01	0.31931193770 01	0.31740654330 01	0.315496844D 01	0.315496844D 01	0.31740854330 01	0.31931193770 01	0.3173902782D 01	0.3078906746D 01	0.29072254390 01	0.27036018190 01	0.2516624445D 01	0.23480554900 01	0.21815982000 01
8 1	0.6204216505p 00	0.1634953597D 00	0.4809067992D-01	0.31304658500-01	0.3456759140B-01	0.35847867810-01	0.28044630930-01	0.15705921170-01	0.56591797230-02	0.6160790438p-03	0.61607904380-03	0.56591797230-02	0.15705921170-01	0.28044630930-01	0.35847867816-01	0.34567591400-01	0.31304658500-01	0.4809067992p-01	0.1634953597p 00	0.6204216505p 00
ħ.	0.24137530590 01	0.29188729410 01	0.3730972025b 01	0.4499123120D OL	0.50096680490 01	0.5182180124D 01	0.50787846900 01	0.48500246630 01	0.4636386293b 01	0.45161883920 01	0.4516188392D 01	0.46363862930 01	0.48500246630 01	0.5078784690b 01	0.5182160124b ot	C.5009668049D 01	0.4499123120b bi	0.3730972025b 01	0.29188729410 01	0.2413753059p of
н э	-0.0497321011B 00	-0.4760283755D 00	-0.2946341922D 00	-0.2592348268D 00	-0.2796290193D 00	-0.2797812728D 00	-0.2382591021D 00	-0.1714661121D 00	-0.9995338218D-01	-0.3248261547D-01	0.32482615470-01	0.99953382180-01	0.17146611210 00	0.2382591021D 00	0.27978127280 00	0.2796290193b co	0.25923482680 00	0.29463419120 00	0.47602837550 00	0.6497321011D 00
н 2	0.10518626520 01	5	0.12175920140 01	0.12900085060 01	0.1312698895D 01	0.1297352475D 01	0.12649783450 01	0.12324360570 01	0.1208594186D 01	0.1196433364D 01	0.11964333640 01	0.1206594186D 01	0.12324360578 01	0.1264978345D 01	0.12973524750 01	0.1312698695D 01	0.12900085060 01	0.1217592014D 01	0.11149449300 01	0.1051862652D 01
- I n	-0.3193994263D 01	-0.3116403752D 01	-0.2909482264D 01	-0.2605907571p 01	-0.2241445500D 01	-0.1845470715D 01	-0.1436956139D 01	-0.1025488377D 01	-0.6145711368D CO	-0.2047109830D 00	0.2047109830D 00	0.61457113680 00	0.1025488377D 01	0.14369561390 01	0.18454707159 01	0.2241445500D 01	0.2605907571D 01	0.29094822640 01	0.31164037520 01	0.31939942630 01
6	-3.8	-3.4	-3.0	-2.6	-2.2	-1.8	٠- ۱- ۱	-1.0	9.0	7.9	0.5	9.0	0.1	<b>*</b> :	<b>*</b> :	2	2.6	3.0	3.4	3.8
_	_	7	~		Ś	•	_	<b>®</b>	•	0	_	~	•	•	•	٠	_	•	•	₽

the sum total of the probabilities assigned to the finite values of  $\,\hat{\theta}_{tr}$ is greater than, or equal to, 0.999999, and \* means that it is greater than, or equal to, 0.99, but less than 0.999999. We can see that none of the rows of the table are marked with \*\*, unlike the other cases in which the number of items is 20 or greater, which we observed in the preceding section. Comparison of the results of the three non-equivalent cases with those of the equivalent case reveals that, around  $\theta = 0.00$ , which equals the common difficulty parameter  $b_g$  for the equivalent case and the mean of the difficulty parameters for each of the three nonequivalent cases, the conditional distribution of  $\theta_{V}$  , given  $\theta$  , is closer to the normality for a wider range of  $\theta$  , as the difficulty parameters spread more widely. If we take the arbitrary criterion as we did in the preceding section, i.e.,  $|\mu_1' - \theta| < 0.03$ ,  $\beta_1 < 0.05$ ,  $|\beta_2-3|$  < 0.50 and  $|\kappa|$  < 0.25, then this criterion is satisfied for the six values of  $\theta$  , -1.0 , -0.6 , -0.2 , 0.2 , 0.6 and 1.0 , for Case 3, while this number reduces to four in Case 2, and two for Case 1 and for the equivalent case.

Figure 5-1 presents the two kinds of regression plus confidence interval for each of the four cases, which were observed in the preceding section for each of the five equivalent tests on the normal ogive and on the three-parameter logistic models. The two additional sets of numbers shown on both the abscissa and the ordinate are the same scale changes for  $a_g=2.00 \quad \text{and} \quad a_g=1.00 \text{ , that are shown in Figures 4-2 through 4-4} \text{ .}$  Note, however, following each scale change, the difficulty parameters in the three non-equivalent cases are also changed proportionally. We can

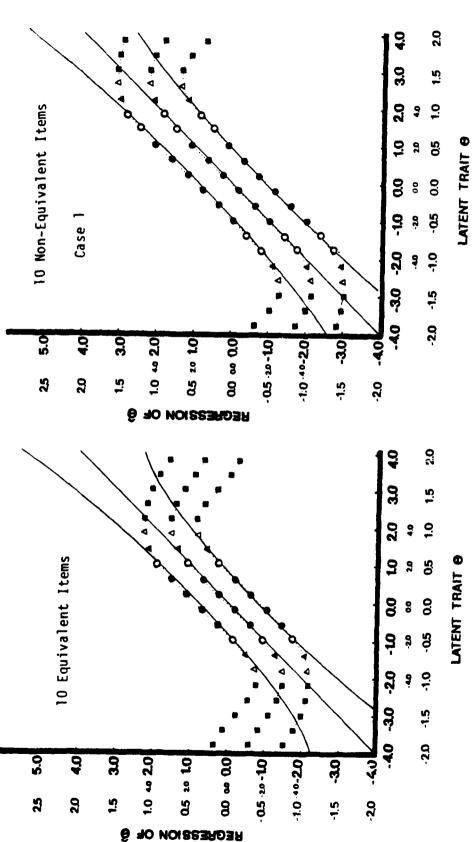


FIGURE 5-1

on  $\theta$  , or  $\mu_1$  , and the Confidence Interval  $(\mu_1^{-\mu})^{1/2}$ ,  $\mu_1^{+\mu_2}$ ) Plotted Against the  $^{ heta}$  , Together with the Asymptotic, Unbiased Regression and the Confidence Interval )]-1/2,  $\theta+\{I(\theta)\}^{-1/2}$ ), for Each of the Four Tests of 10 Items on the Normal Ogive Model ag = 0.50. For the Equivalent Case, bg = 0.00, and the Three Sets of Difficulty Parameters for the Three Non-Equivalent Cases Are as Shown in Table 5-1 Twenty Points of  $(\theta - \{I(\theta)\}^{-1/2})$ Regression of

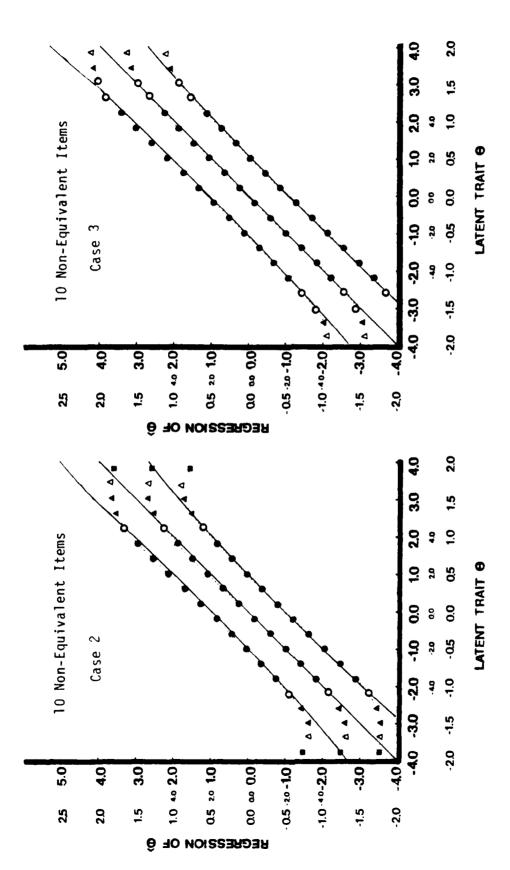


FIGURE 5-1 (Continued)

see that in each case, those solid circles, which are based upon the sum total of the probabilities assigned to the finite values of  $\hat{\theta}_V$  greater than, or equal to, 0.99, practically lie on the asymptotic regression and the confidence interval, i.e.,  $\theta$  and  $(\theta - \{I(\theta)\}^{-1/2}, \theta + \{I(\theta)\}^{-1/2})$ . There are substantial differences in the range of  $\theta$  for which this is the case, however. This interval of  $\theta$  is (-2.2, 2.2) for Case 3 of the non-equivalent items, while it is only (-0.6, 0.6) for the equivalent case.

The square root of the test information function of each of the three non-equivalent cases is shown by a dashed line in each graph, in both Figures 5-2 and 5-3. In the same figures, also presented by solid lines are the square roots of the test information functions of the ten item tests which are based upon the three-parameter logistic model with the same parameters  $a_{\rm g}$  and  $b_{\rm g}$  and the third parameter,  $c_{\rm g}$  = 0.20 and  $c_{\rm g}$  = 0.25 , respectively. The critical values,  $\theta_{\rm g}$  , of the first items of the three tests are -0.3646728290004818D 01 , -0.4546728290004819D 01 and -0.5446728290004819D 01 for  $c_{\rm g}$  = 0.20 , and -0.3515467362739969D 01 , -0.4415467362739969D 01 and -0.5315467362739969D 01 for  $c_{\rm g}$  = 0.25 . In Case 1, the values of  $\theta_{\rm g}$  increase by 0.6 as the value of the difficulty parameter increases, while in Cases 2 and 3 the steps are 0.8 and 1.0 , respectively.

If we take the strategy not to use the informaton obtained from item g for the interval of  $\theta$ ,  $(-\infty, \theta_g)$ , then the square root of the test information function will be reduced to the curve plotted by a dotted line in each of the six graphs of Figures 5-2 and 5-3. In this way, we can

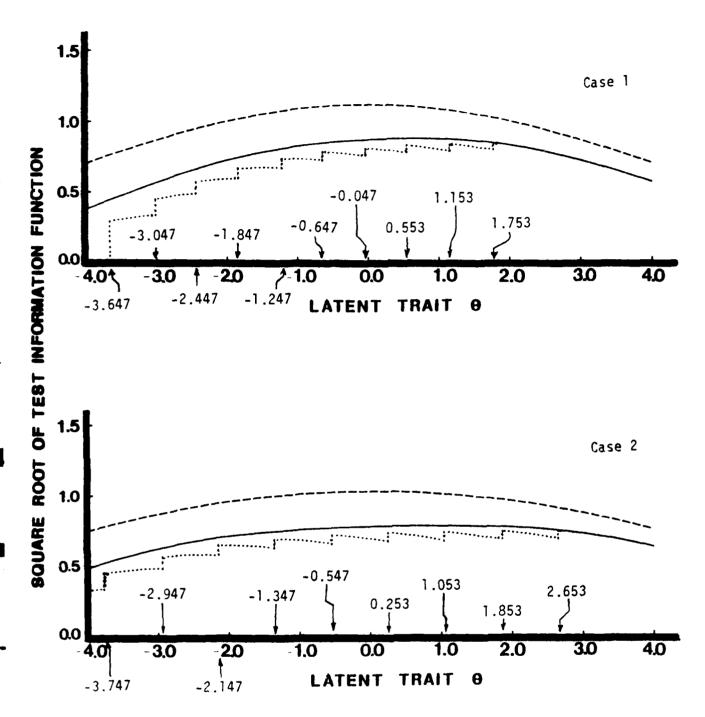


FIGURE 5-2

Square Roots of Test Information Functions of Each of the Three Tests of Ten Non-Equivalent Items in the Normal Ogive Model (Dashed Line) and in the Three-Parameter Logistic Model (Solid Line). The Latter Is Reduced to the One Drawn by Dots When Each Item Information Function Is Truncated at  $\theta_g$ , Whose Value Is Shown in Each Graph.  $c_g = 0.20$ 

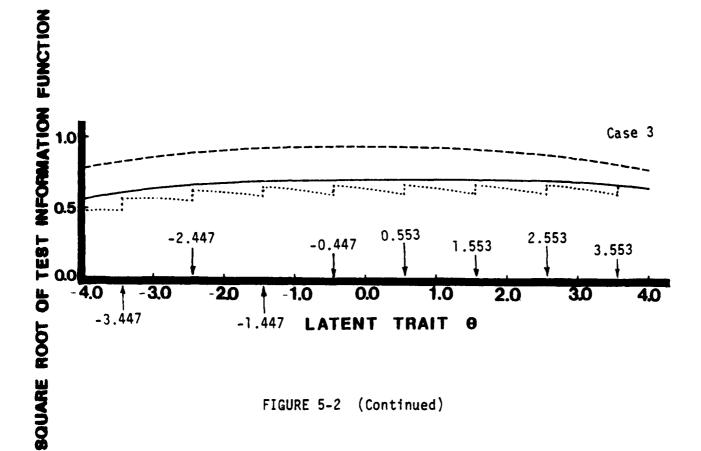


FIGURE 5-2 (Continued)

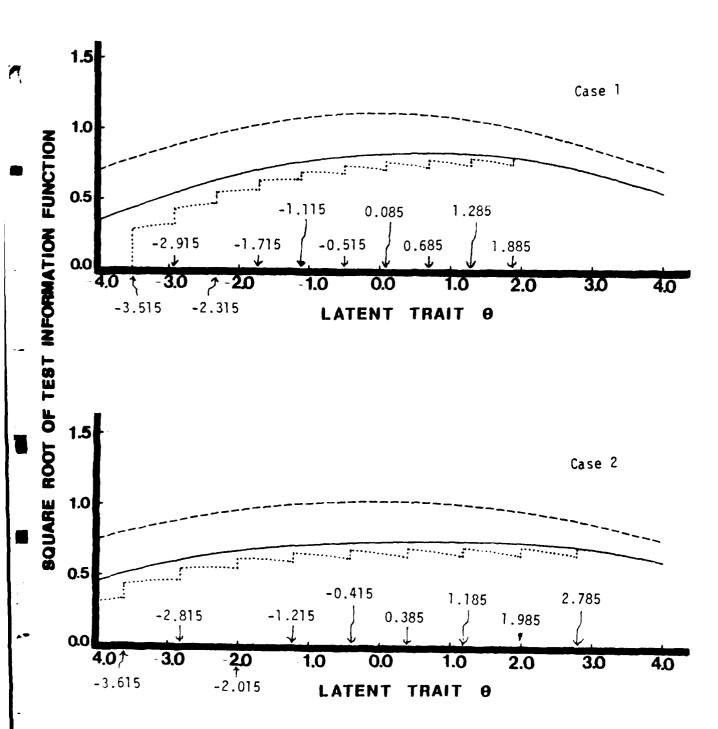


FIGURE 5-3

Square Roots of Test Information Functions or Each of the Three Tests of Ten Non-Equivalent Items in the Normal Ogive Model (Dashed Line) and in the Three-Parameter Logistic Model (Solid Line). The Latter Is Reduced to the One Drawn by Dots When Each Item Information Function Is Truncated at  $\theta_{\rm g}$ , Whose Value Is Shown in Each Graph.  $c_{\rm g}=0.25$ 

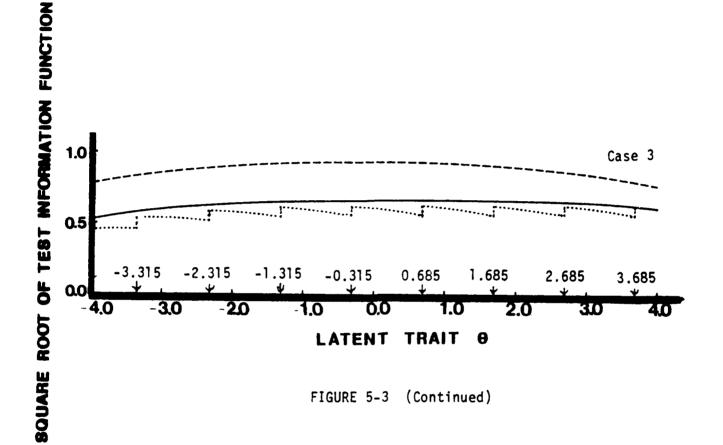


FIGURE 5-3 (Continued)

avoid multi-modal likelihood functions which may occur for some response patterns if the items follow the three-parameter logistic model. Further investigation as to the merit and demerit of this strategy is yet to come, however, and its results are left to another paper. The corresponding six graphs of the test information functions are presented as Figures A-2 and A-3 in Appendix.

## VI Discussion and Conclusions

The three-parameter logistic model was compared with the normal ogive model using hypothetical tests of equivalent items, mainly with respect to the speed of convergence of the conditional distribution of the maximum likelihood estimate, given  $\theta$ , to the normality, and it was found out that the effect of noise caused by random guessing is substantial, especially for the values of  $\theta$  less than the critical value  $\theta_g$ . Some observations were made on the normal ogive model as to how the interval of  $\theta$  for which the approximation of the conditional distribution by the normality is acceptable can be enhanced by using non-equivalent test items.

This is just a beginning of the investigation about how and in what ways we can amend the deficiencies of the three-parameter logistic model which are caused by random guessing. The effective use of the critical value  $\frac{c}{g}$  may be one solution to the problem, which will be investigated further.

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## APPENDIX

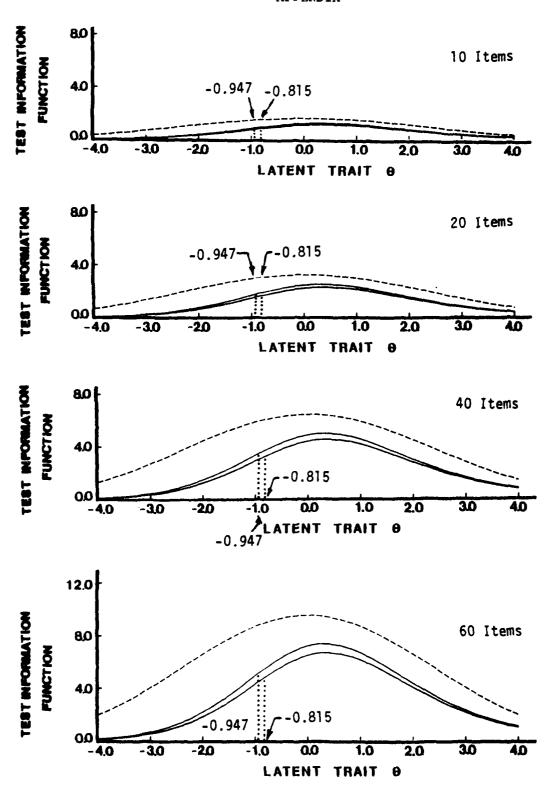


FIGURE A-l Test Information Functions of Each of Eleven Tests of Equivalent Items, in the Normal Ogive Model (Dashed Line), and in the Three-Parameter Logistic Model (Solid Lines) with  $c_g$  = 0.20 and  $c_g$  = 0.25 . The Two Values of the Common  $\theta_g$  Are Shown.

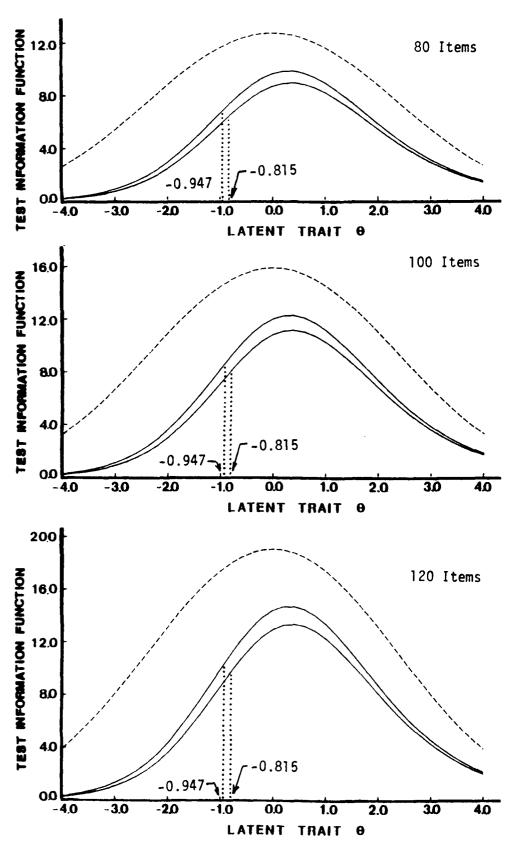
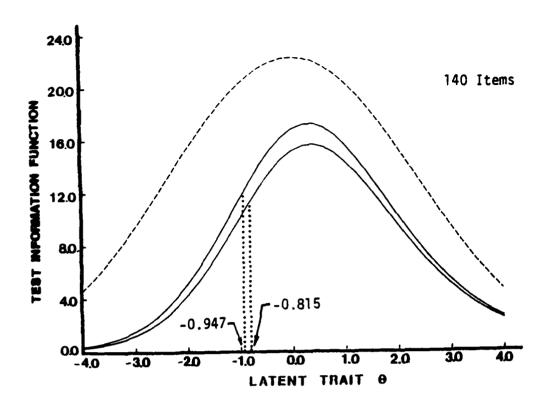


FIGURE A-1 (Continued)



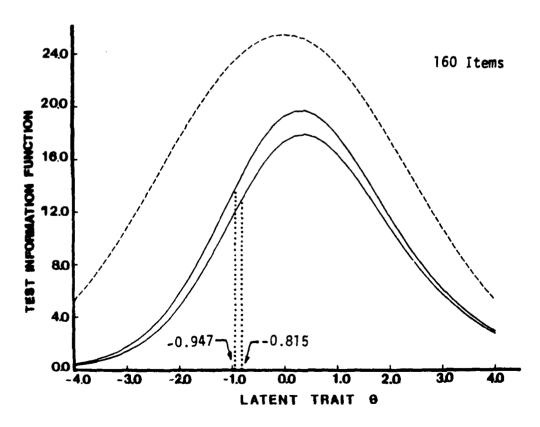


FIGURE A-1 (Continued)

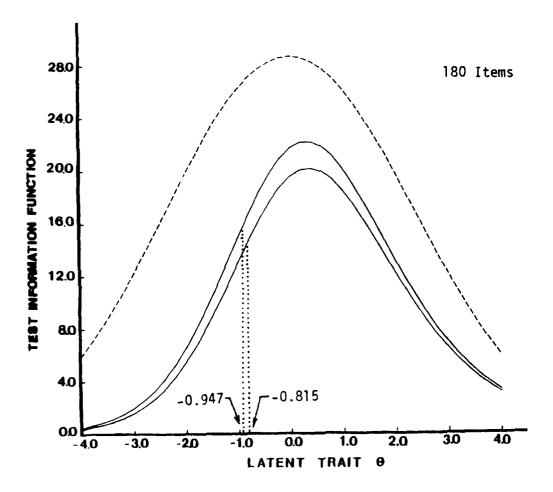


FIGURE A-1 (Continued)

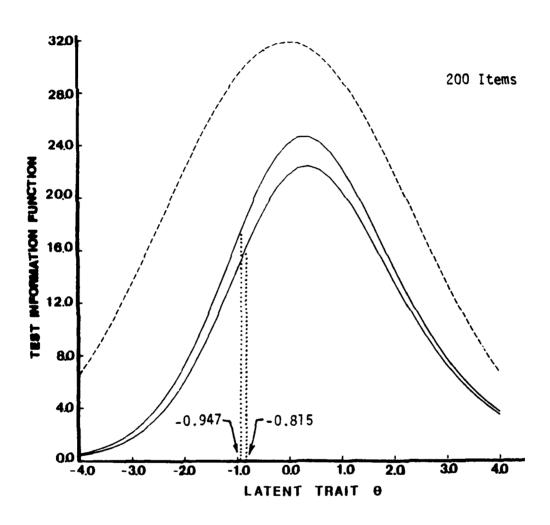
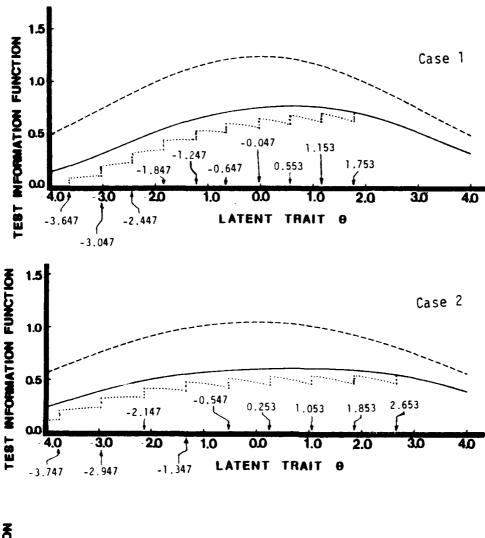


FIGURE A-1 (Continued)



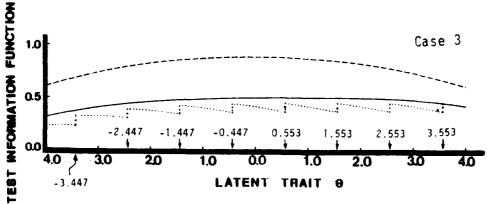
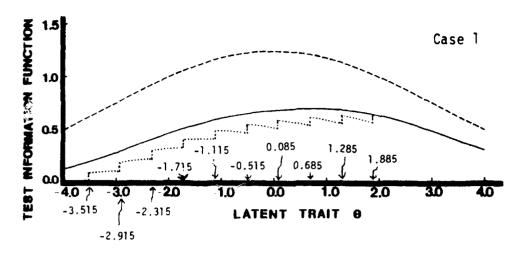


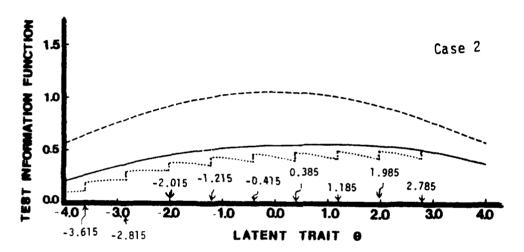
FIGURE A-2

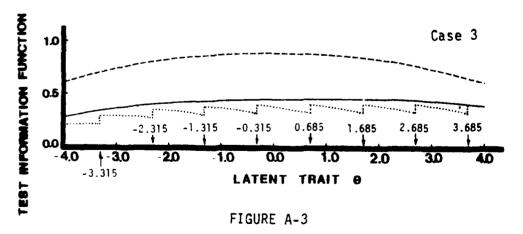
Test Information Functions of Each of the Three Tests of Ten Non-Equivalent Items in the Normal Ogive Model (Dashed Line) and in the Three-Parameter Logistic Model (Solid Line). The Latter Is Reduced to the One Drawn by Dots When Each Item Information Function Is Truncated at  $\theta$  , Whose Value Is Shown in Each Graph.  $^{\rm g}$ 

 $c_g = 0.20$ 



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Test Information Functions of Each of the Three Tests of Ten Non-Equivalent Items in the Normal Ogive Model (Dashed Line) and in the Three-Parameter Logistic Model (Solid Line). The Latter Is Reduced to the One Drawn by Dots When Each Item Information Function Is Truncated at  $\theta$  , Whose Value Is Shown in Each Graph.

 $c_g = 0.25$ 

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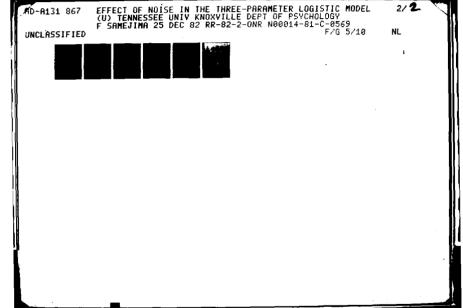
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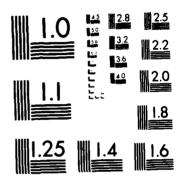
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